

Transient Tests of A/C System Performed on a Caravan 1997

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ACRC CR-12

December 1997

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**TRANSIENT TESTS OF A/C SYSTEM
PERFORMED ON A CARAVAN 1997**

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November, 1997

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Prepared for: Dayton Thermal Products
as Part of Proposal File No. 2578

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TRANSIENT TESTS OF A/C SYSTEM PERFORMED ON A 1997 CARAVAN

Introduction

This report presents results obtained during testing of a 1997 Chrysler Caravan brought to our labs from Chrysler Auburn Hills Technical Center. This report follows the same format as the one previously sent to Dayton Thermal Products and Chrysler on tests performed on a 1994 Caravan vehicle (September 97). In addition to the information presented in the previous report acceleration measurements in the plate evaporator and in the tube downstream of the evaporator were taken. Cabin temperature and humidity are now also reported.

These tests intend to determine the variation of some parameters, mainly refrigerant mass flow and velocity, on the low side of the A/C system during start up conditions.

The tests were designed to capture the rapid changes in conditions at the evaporator outlet during air conditioning system start up. In particular we were interested in finding the range of refrigerant flow rates under transient operation to determine conditions at the plate evaporator that might produce acoustic resonance.

Instrumentation

Instrumentation of the suction line hose was performed by inserting an instrumented section in the suction line after the hose was cut. The instrumented section was inserted after the expansion valve and before the compressor. Five different measurements were made at this point:

- 1) Differential pressure across a venturi.
- 2) Suction manometric pressure.
- 3) Suction temperature.
- 4) Reference temperature
- 5) Clutch voltage

In addition to these measurements, acceleration readings were taken by two accelerometers inserted one in the plate evaporator at the third plate from the access hole to the evaporator behind the glove compartment and the other accelerometer was placed in the suction tube downstream of the evaporator and upstream of the expansion valve.

Pressure was measured by using two Validyne Engineering differential pressure transducers model (DP15); one using a diaphragm of -20 to 20 psid. This

transducer was connected to the high and low pressure ports of a Gerand $\frac{3}{4}$ " 440 Venturi flow meter. The other pressure transducer had a diaphragm, which gave it a range from -320 to 320 psid. This transducer was connected to the high pressure port of the Venturi flow meter on one side and open to the atmosphere on the other. The pressure transducers, according to the manufacturer, have a frequency response of up to 1 kHz, but it is more likely that this response will be limited by the acoustic resonance frequency of the lines connecting the transducers, therefore these lines were as short as possible (approx. 4").

Temperature was measured using a specially ordered high speed thermocouple, which according to the manufacturer (Nanmac Co.) has a response time of 20 ms. The reference temperature for this thermocouple was obtained using a two-terminal temperature transducer chip model AD590 from Analog Devices. This transducer was calibrated in the laboratory and was used for two purposes:

- 1) To provide a reference temperature for the above thermocouple since it was mounted in thermal contact with the connection of the thermocouple to copper instrument cables.
- 2) Measure the outdoor temperature (Auto Lab temperature where car was tested).

Two PCB accelerometers one model 352B66 miniature accelerometer with a sensitivity of 100 mV/g and the other model 353B16 with a 10 mV/g sensitivity were installed as described above. The accelerometers were mounted in these positions to try to pick up any acoustic resonance or other type of noise generated and/or transmitted in the plate evaporator or in the evaporator tubes.

Voltage to the compressor clutch was measured after passing it through a voltage divider to reduce the signal sent to our data acquisition system. This signal was used as a way to determine when the compressor started to operate.

Finally all the sensors were connected to a high speed data acquisition system. The sample frequency used was 200 Hz. for temperatures, pressures and clutch voltage and 50 kHz. for acceleration. This sampling rate is sufficient to capture the transient phenomena based on results of previous tests performed on the 1994 Caravan at much higher sampling rates.

The 200 Hz. data channels were filtered with a low pass filter with a 66.7 Hz. band pass. The acceleration data filter bandwidth was 14,500 Hz. Photographs of the test apparatus are shown in appendix C.

Tests Description

After recovering the refrigerant from the system, the original suction line hose was cut and an instrumented section was inserted. Then the system was charged with refrigerant. Two different charges were used during testing; first approx. half the total charge was used (500g) then the full charge was used (1000 g).

Tests Performed

Name:	Test Description:
Test97_1	First the cabin was heated using the vehicle heating system with re-circulation on. Humidity was added to the cabin by spraying fine water mist into the warm air. Conditions inside the cabin for this test were 124 °F with approx. 88 %RH. Charge in the system is 500g. The car was running at idle rpm conditions i.e. approx. 800 rpm.
Test97_2	Similar conditions to previous test but now running at 2500 rpms.
Test97_3	Conditions inside the cabin: 116 °F, approx. 92%RH, charge of 1000g, running at idle rpms conditions.
Test97_4	Conditions inside the cabin: 122 °F, approx. 95%RH, charge of 1000g, running at 2500 rpms conditions.
Test97_5	<p>During tests 1 to 4 the A/C system settings were: re-circulation on, temperature sliding controls to hot, and fans directed to feet. These settings at maximum fan speed were used to warm the cabin, then the fan speed was reduced to the minimum and the data acquisition system and compressor were turned on. Tests 5, 6 and 7 were performed differently, after the cabin was warm and ready, re-circulation was turned off, the temperature sliding controls were set to cool and then the data acquisition system and compressor were turned on. For this test:</p> <p>Conditions inside the cabin: 128 °F, approx. 90%RH, charge of 1000g, running at idle rpms conditions.</p>
Test97_6	Conditions inside the cabin: 129 °F, approx. 82%RH, charge of 1000g, running at 2500 rpms conditions.
Test97_7	Conditions inside the cabin: 129 °F, approx. 68%RH, charge of 1000g, running at 4500 rpms conditions.

Results

Appendix A shows the measured and estimated data for each test. Clutch voltage, accelerations, suction temperature, differential pressure across the venturi, suction pressure, and reference temperature were directly plotted from data. Mass flow, density and average velocity assuming the smallest circuit area equal to 6 1/2 plates were estimated using the equations presented in appendix B.

Our examination of the data shows the following:

- 1) All measured data seems to be reasonable.
- 2) The evaporator of this vehicle did not whistle during this series of tests.
- 3) The acceleration measurements do not show any harmonic content in the expected acoustic resonance region.
- 4) Flow velocities estimated for an evaporator circuiting including a pass with 6 1/2 channels formed by the plates are shown in Appendix A. These flow velocities are in the range where acoustic resonance has been detected in the laboratory for this type of plate evaporator. Results presented in (1) could be consulted to see acceleration measurements on a single plate subject to similar flow rates.
- 5) Flow velocities measured for this vehicle are considerably higher than those measured for the 1994 Caravan. Average peak flow velocity for the 1994 Caravan is approx. 15 m/s for a 6 1/2 pass section vs. approx. 21 m/s for these tests.
- 6) Acceleration power spectra obtained from the acceleration time history data taken at the side of the plate evaporator does not show conclusive signs of acoustic resonance in the evaporator.

Appendix A also shows graphs of suction and saturated temperatures of the different tests performed. Suction temperatures are measured directly as presented in appendix A (Shown as the darker line). The saturated temperatures were estimated using suction pressures and a R134a curve fit shown at the end of appendix B. The curve fit was obtained with the use of the package Engineering Equation Solver (EES).

As can be seen in these graphs for tests 1 and 2 there is always superheated vapor refrigerant during the approx. 40 seconds that the test lasts. For the rest of the tests i.e. tests 3-7 there is always a region in which saturation and suction temperature are close together which would correspond to saturated or two-

phase conditions. In this region all estimated values are not correct (i.e. mass flow, density and plate evaporator flow velocity).

Appendix B shows the set of equations used to calculate mass flow and density. Density calculations are valid only for superheated refrigerant. Density is needed to estimate mass flow and with mass flow, the velocity can be estimated once the cross sectional area of the 6 ½ refrigerant channels of the first circuit for the plate evaporator are determined.

Conclusion

These tests followed the procedures developed in (2) for measuring the high speed transient behavior occurring during A/C system start up. This vehicle has been shown to produce some hissing sounds right after A/C system start up. Tests results reported here did not indicate what is the source of this problem. Further tests with accelerometer placed at the outlet plates of the evaporator and at the inlet tube could improve the measurements. While no whistling was observed in these tests, observed refrigerant velocities are in the range of velocities that produce whistling in the laboratory. The initiation of whistling or acoustic resonance has been shown to produce some hissing sounds. Preliminary tests with an initial high pressure in the system produced by maintaining a very high temperature in the condenser were shown to emit distinctive noise each time the compressor clutch engaged. Laboratory testing of an expansion valve/plate evaporator assembly should be able to provide the information necessary to determine the cause of the hissing.

Reference

- 1) Hrnjak P., Miller N.R., Rodarte E., "Acoustic Resonance in Plate Evaporators" ACRC report, August 1996.
- 2) Hrnjak P., Miller N.R., Rodarte E., "Transient Tests of A/C system Performed on a Caravan 1994" ACRC report, September 1997.

Appendix A: Graphs of Tests

Test97_1

Test97_2

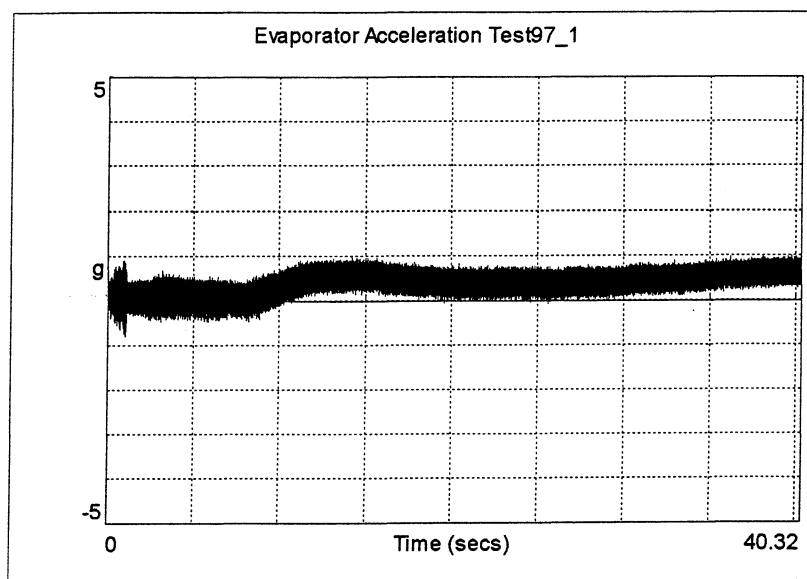
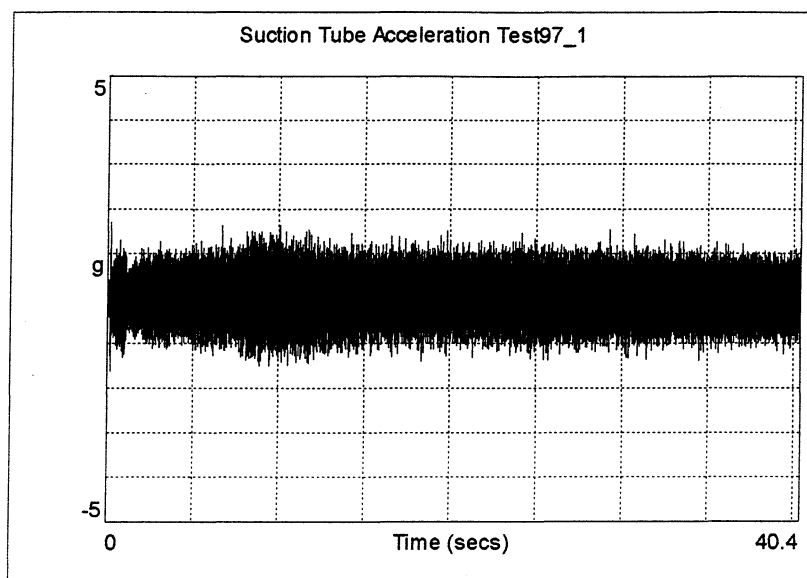
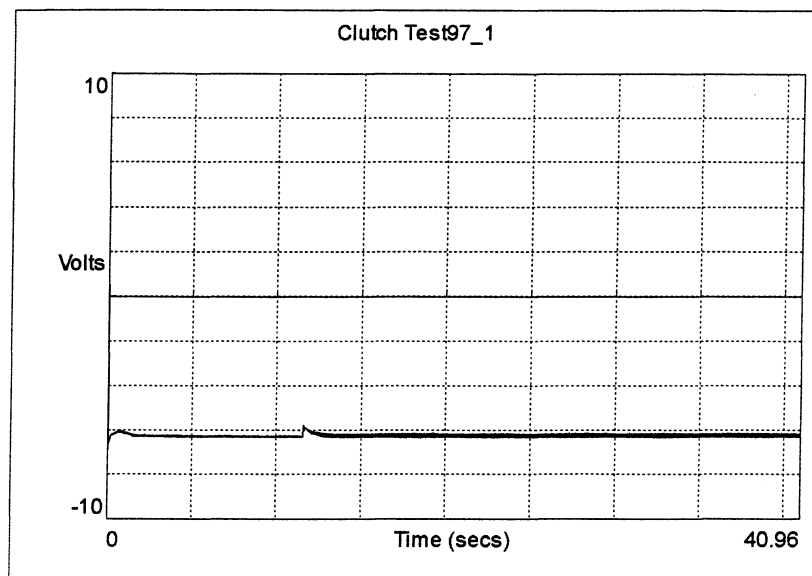
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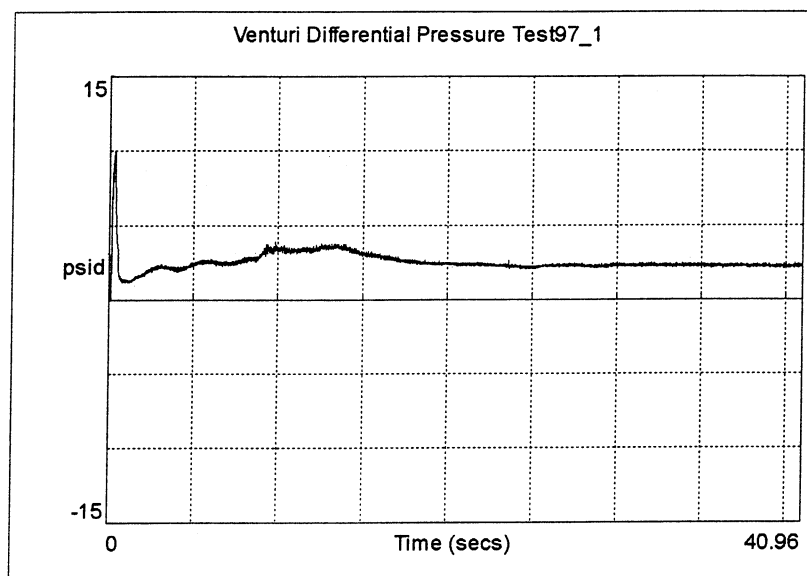
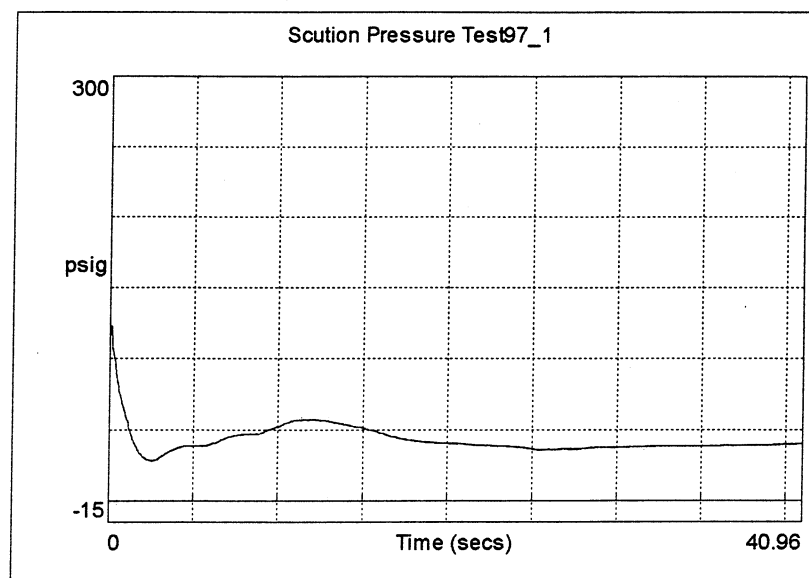
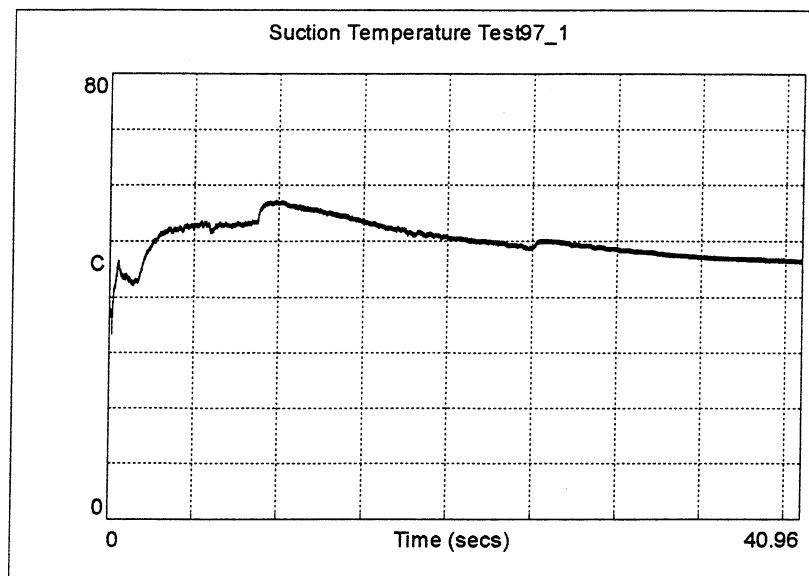
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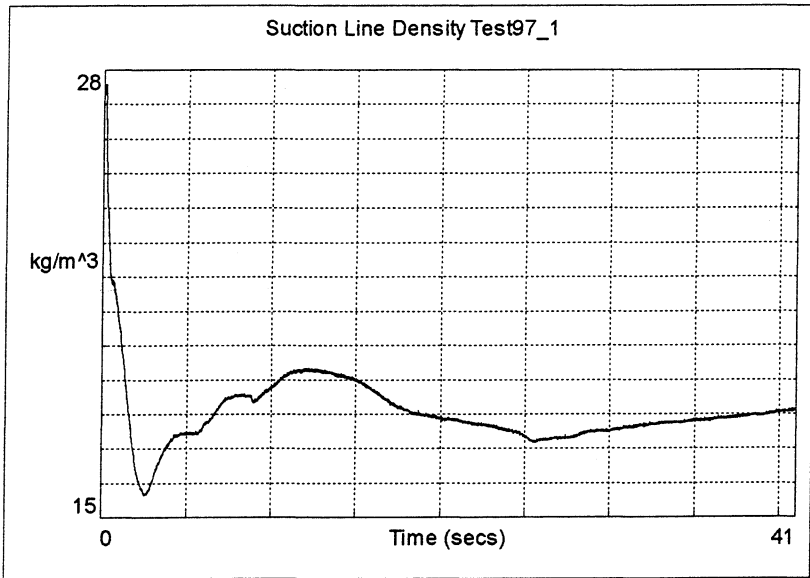
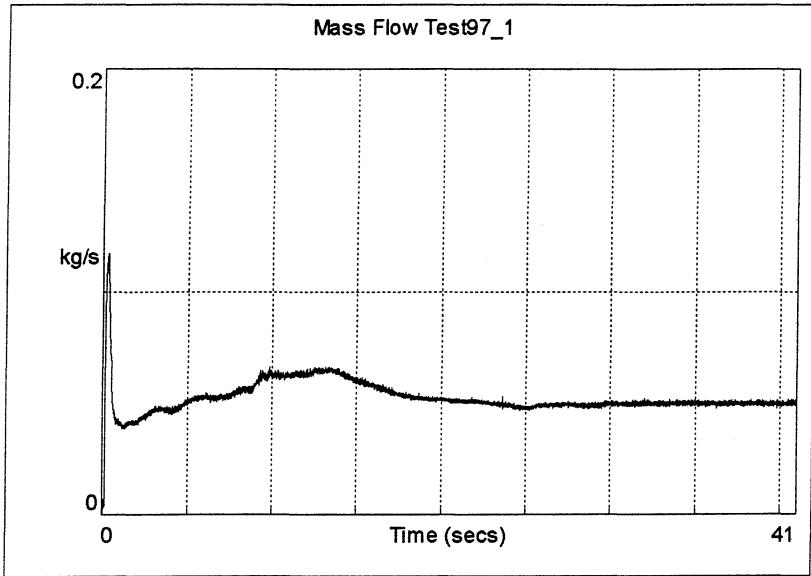
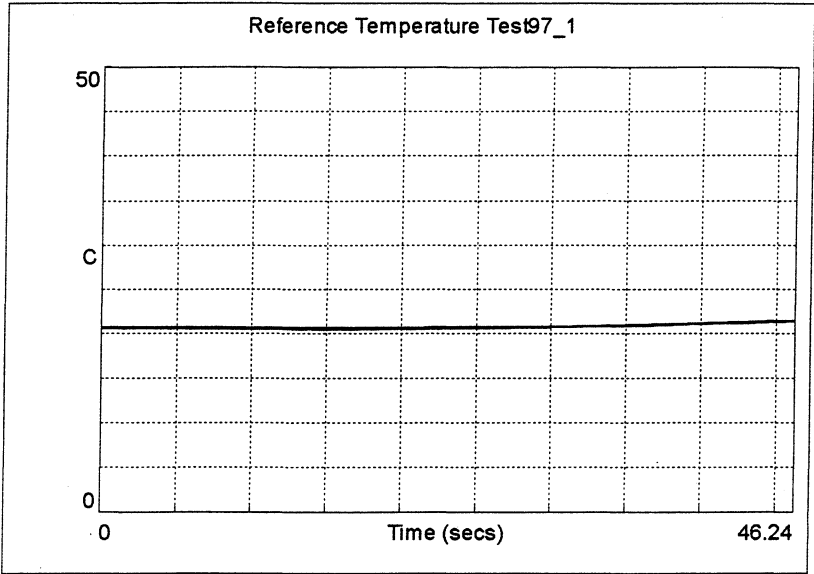
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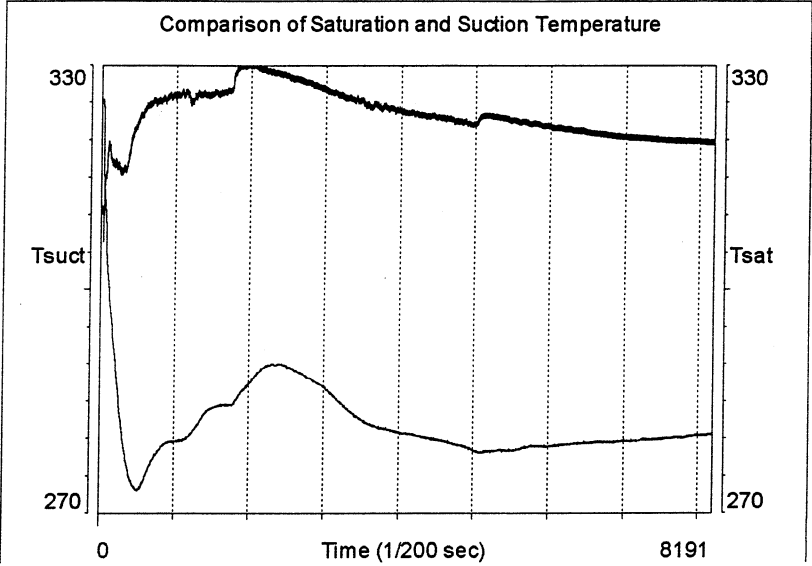
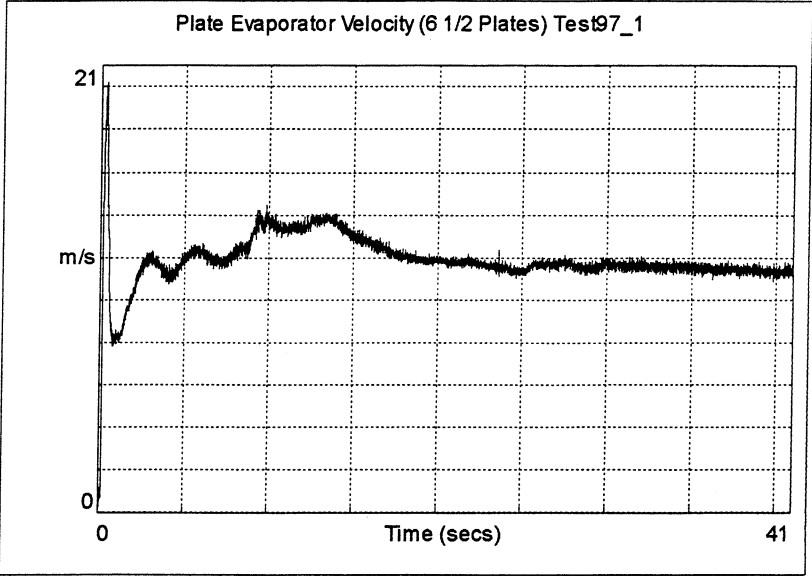
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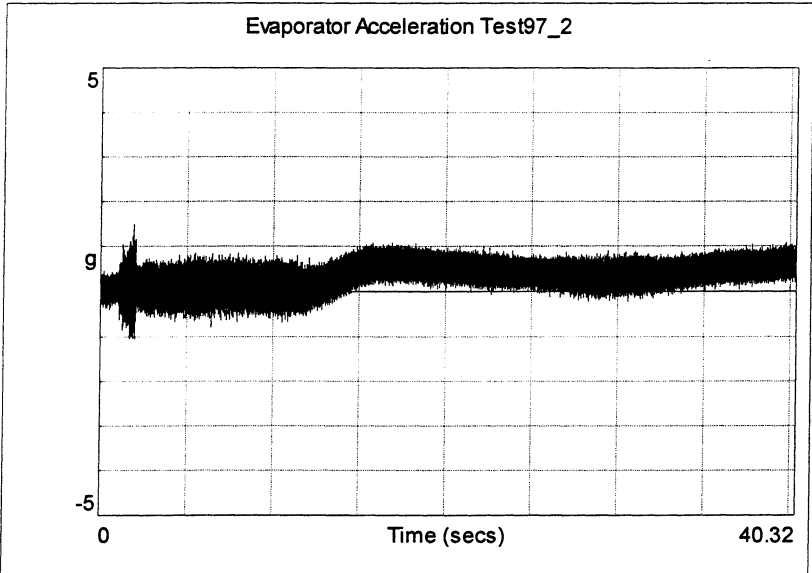
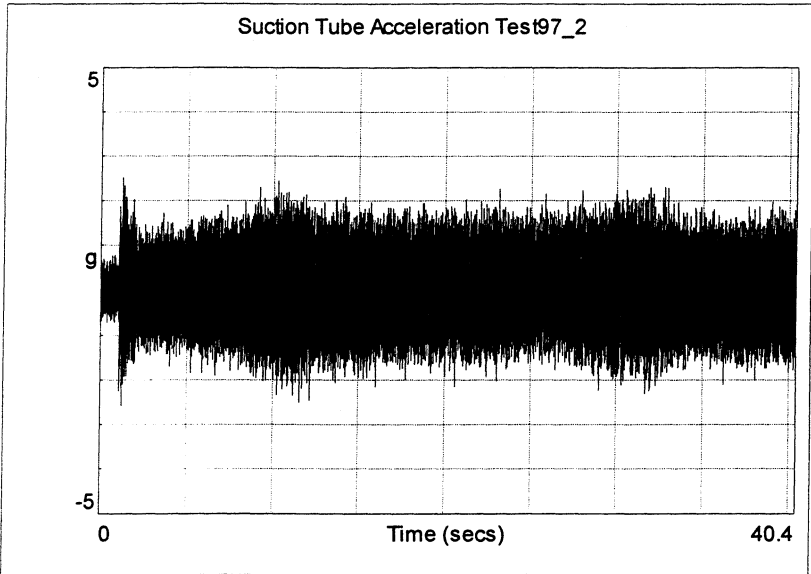
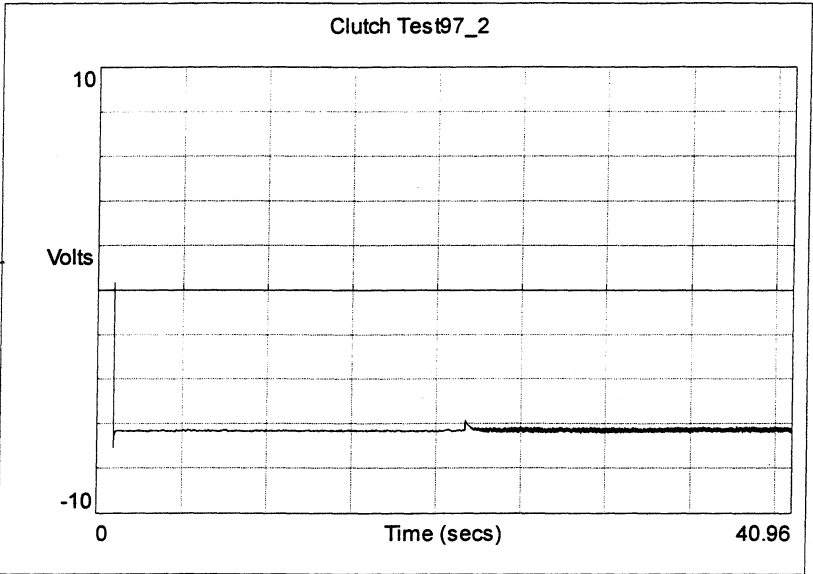
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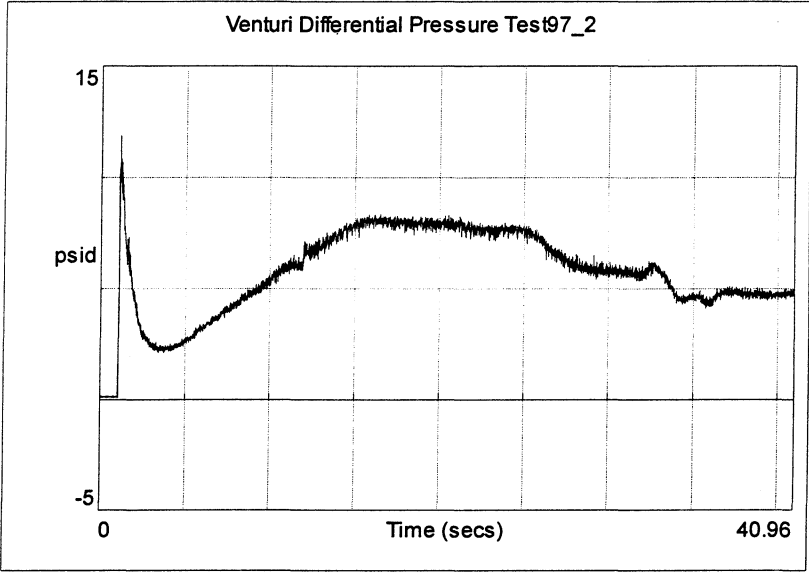
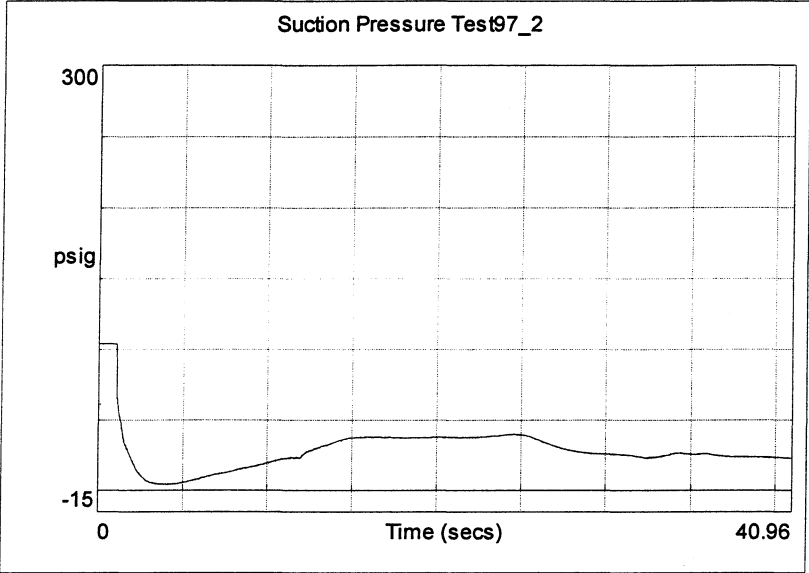
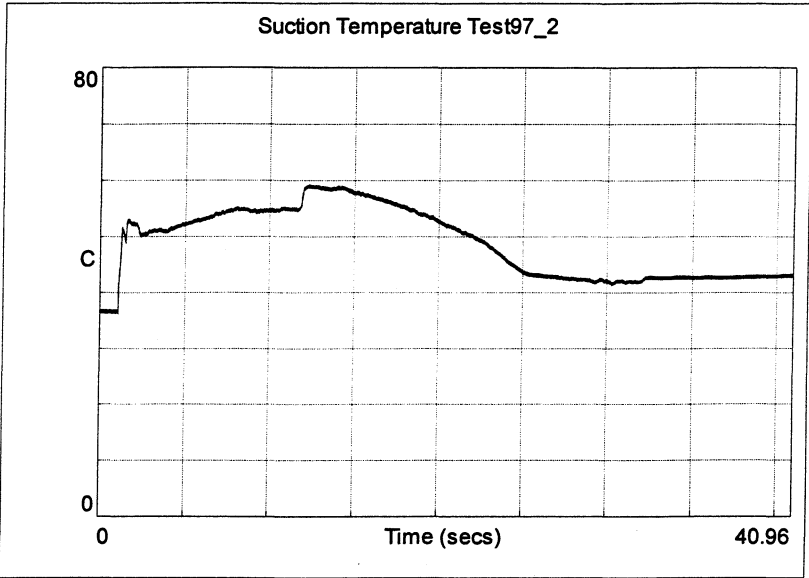




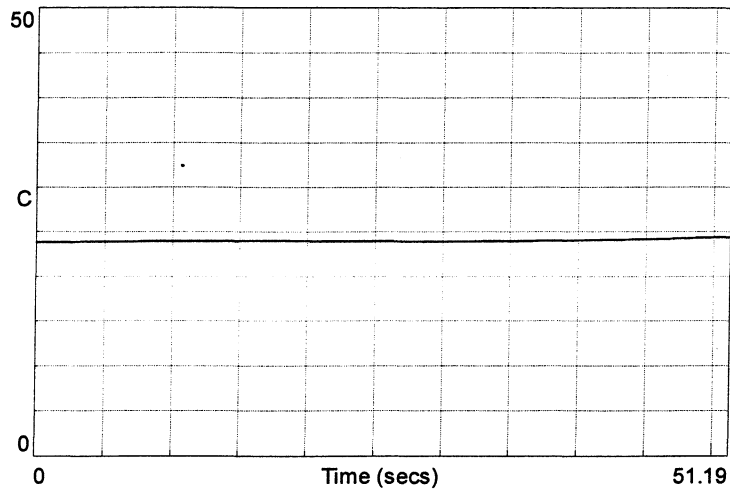




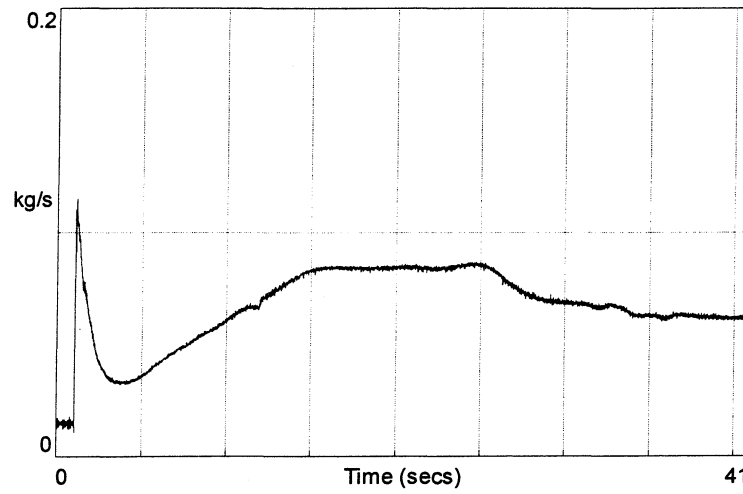




Reference Temperature Test97_2



Mass Flow Test97_2



Suction Line Density Test97_2

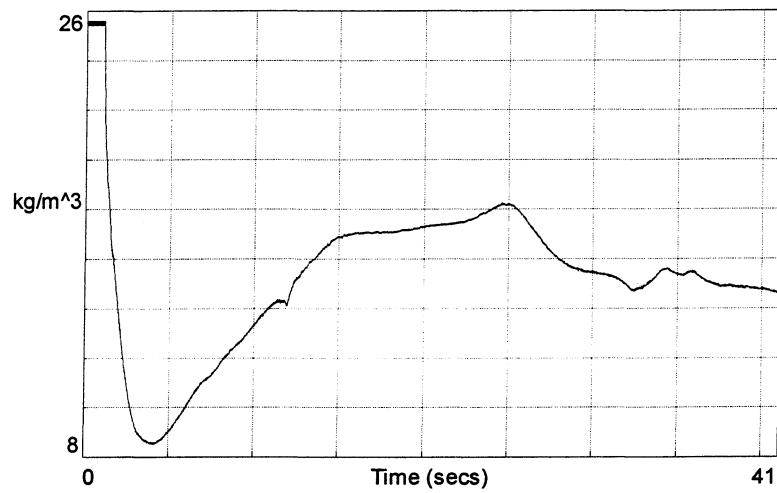
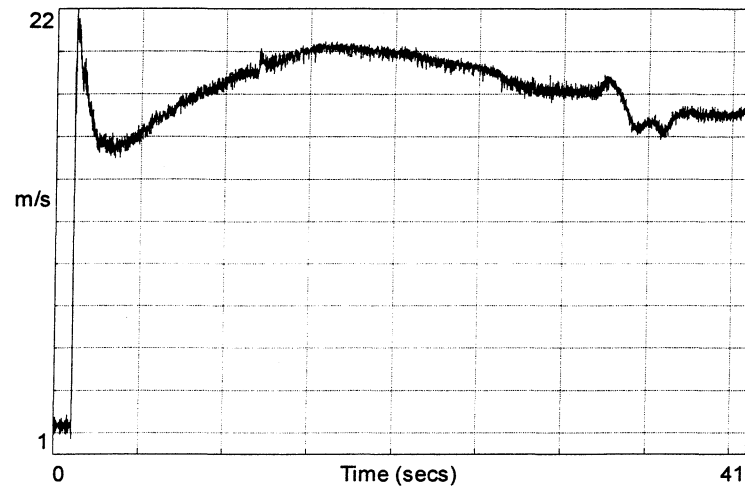
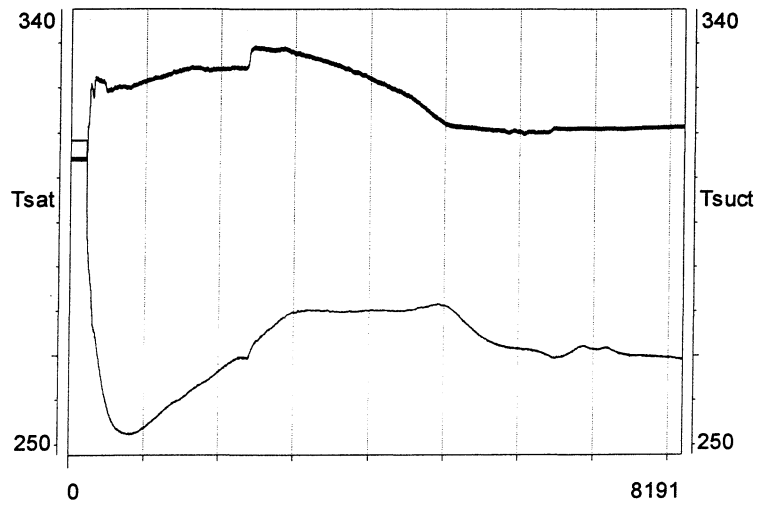


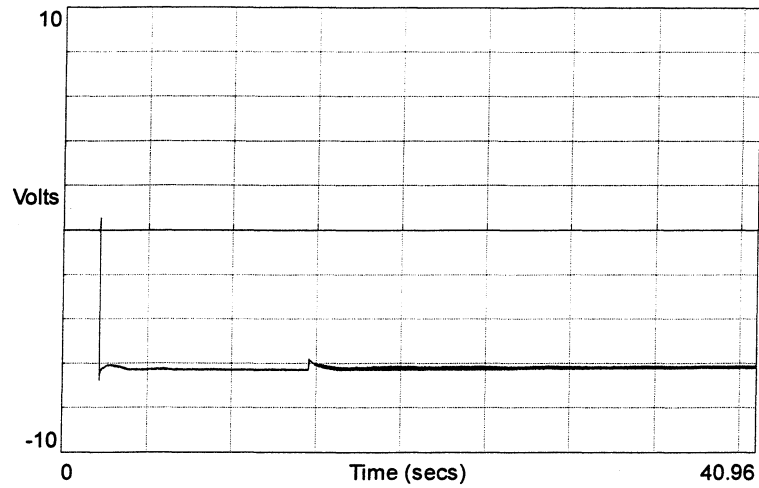
Plate Evaporator Velocity (6 1/2 Plates) Test97_1



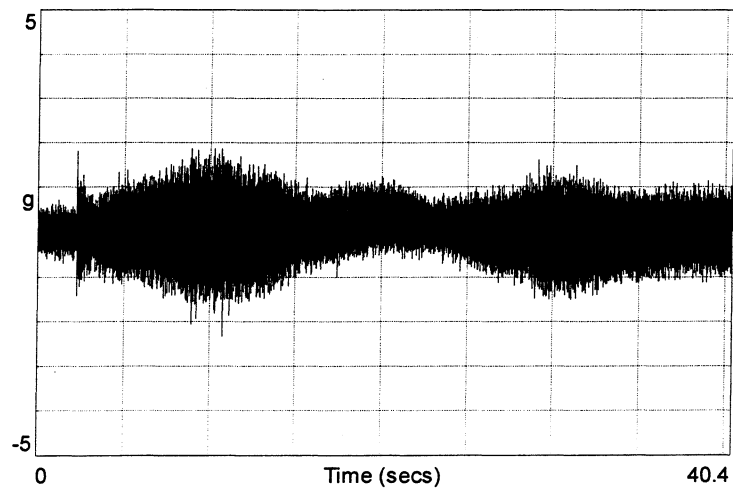
Comparison of Saturation and Suction Temperature Test97_2



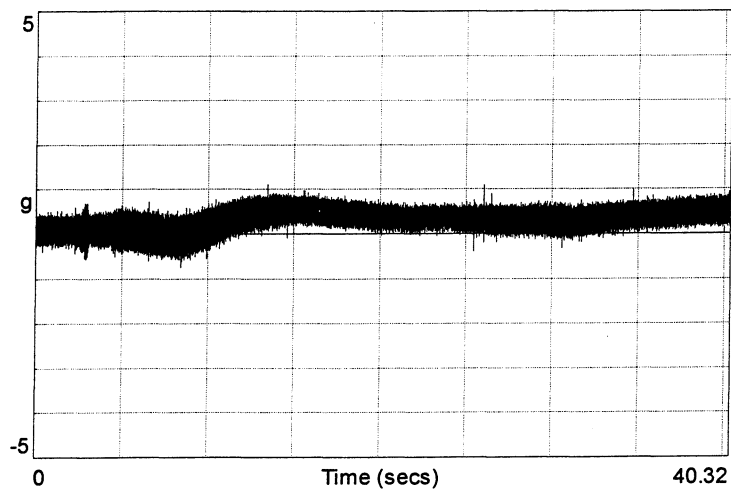
Clutch Testt97_3

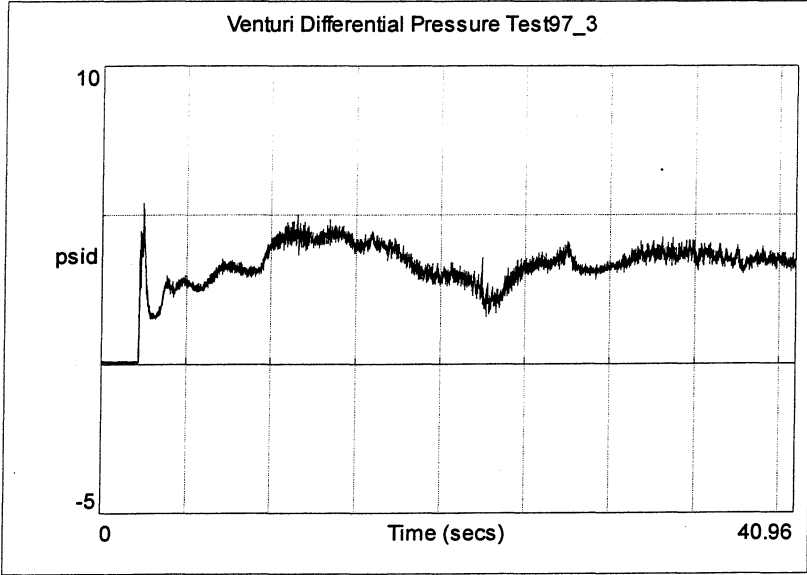
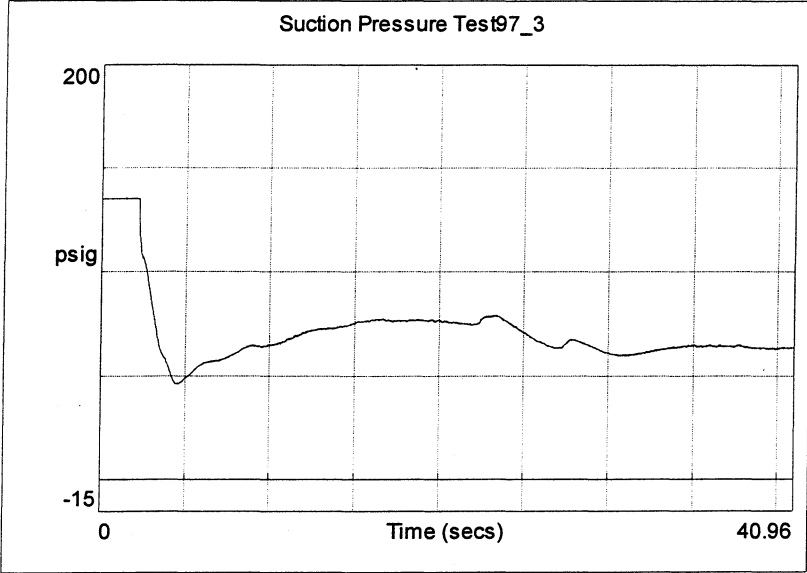
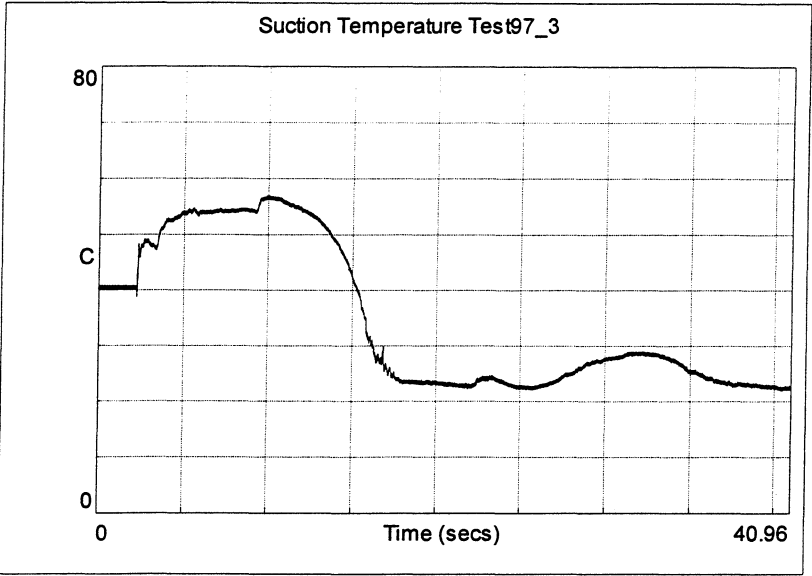


Suction Tube Acceleration Testt97_3

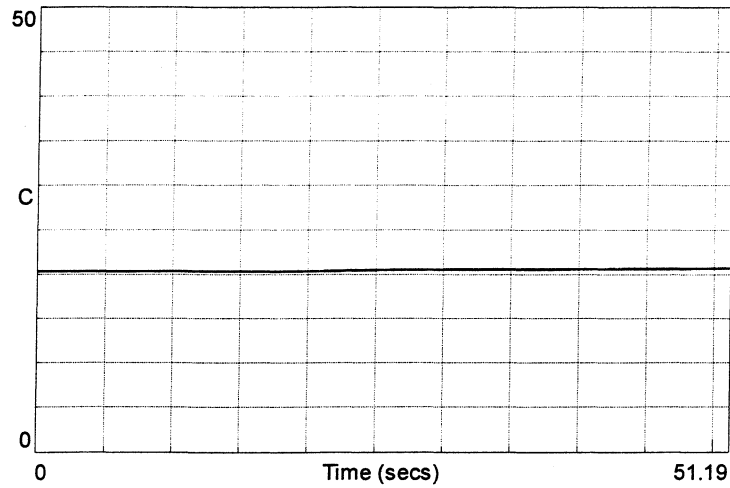


Evaporator Acceleration Testt97_3

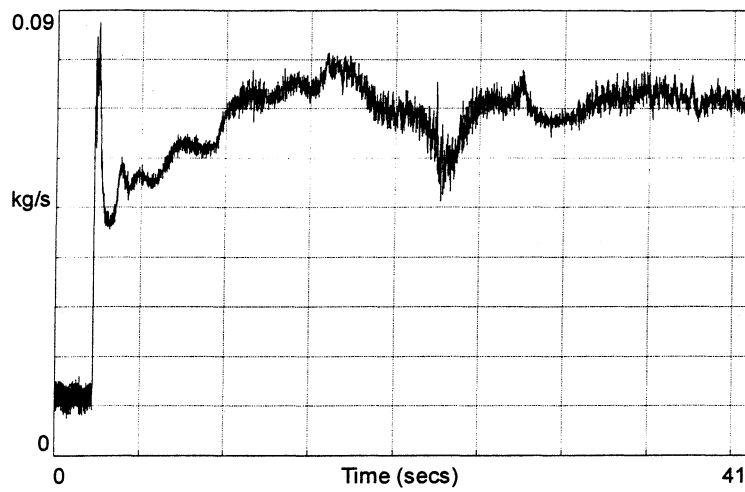




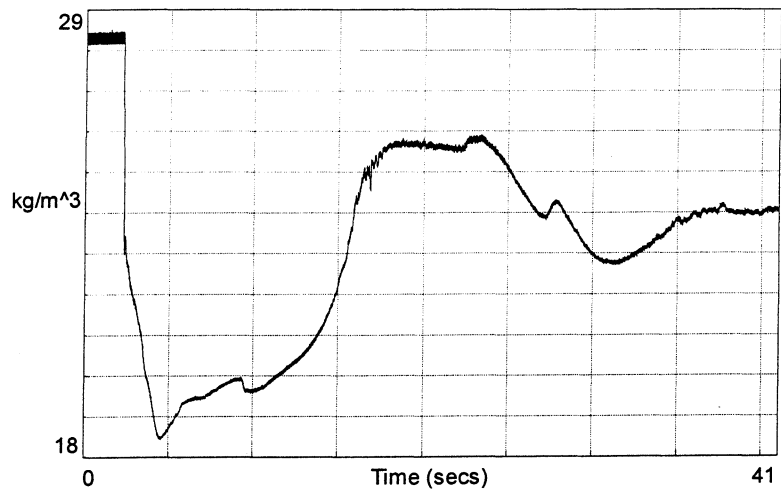
Reference Temperature Test97_3

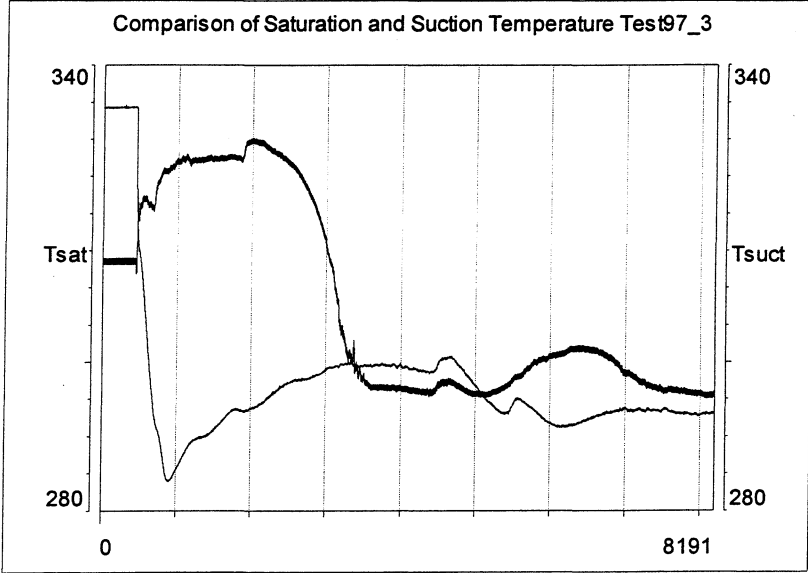
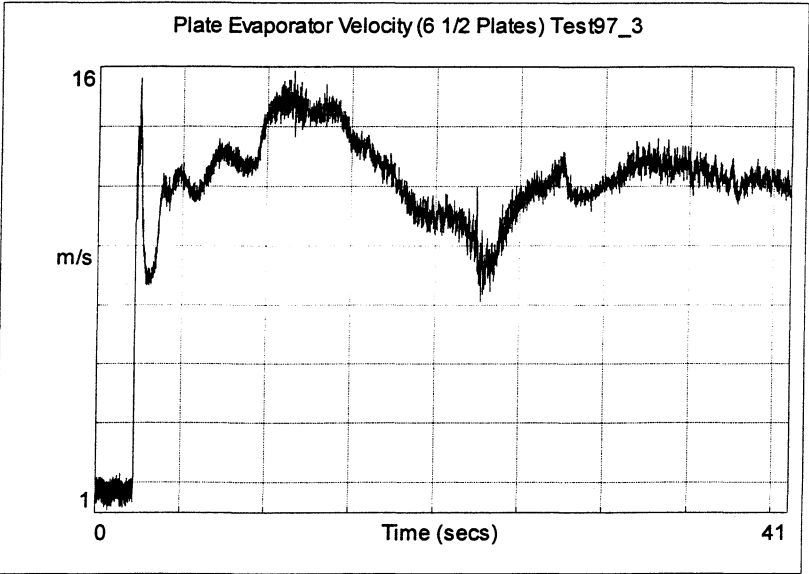


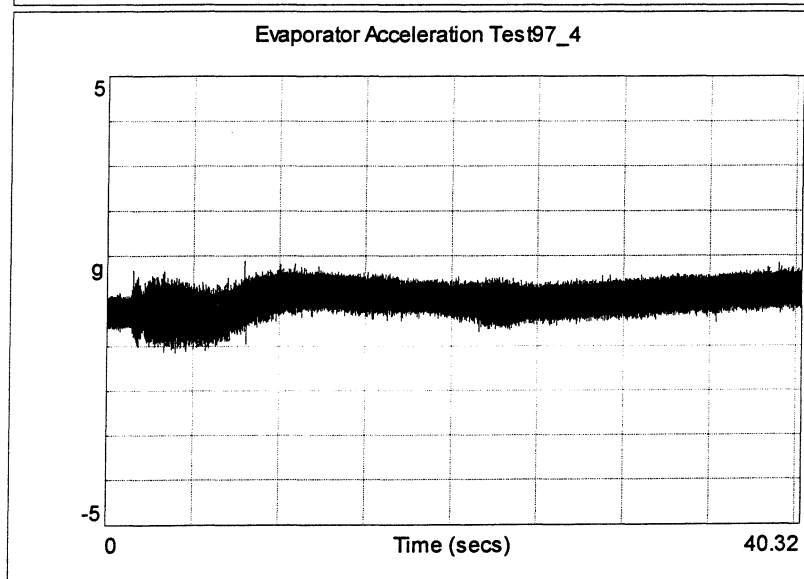
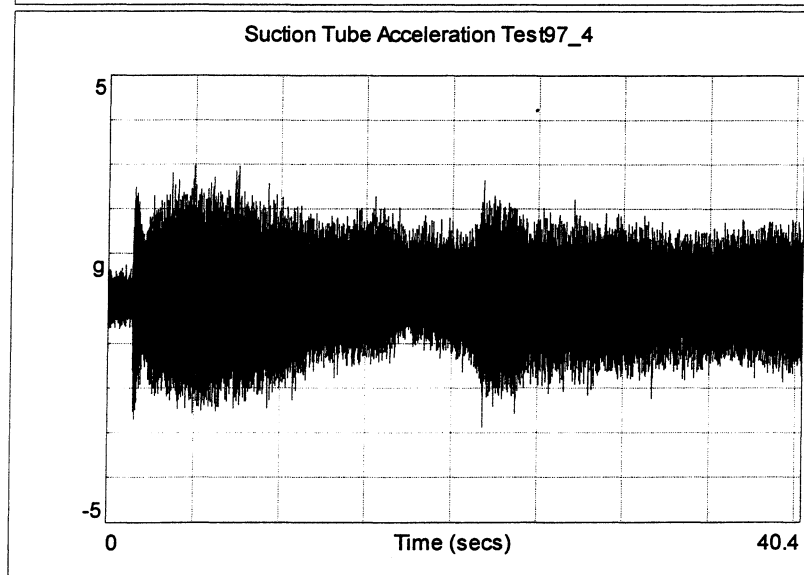
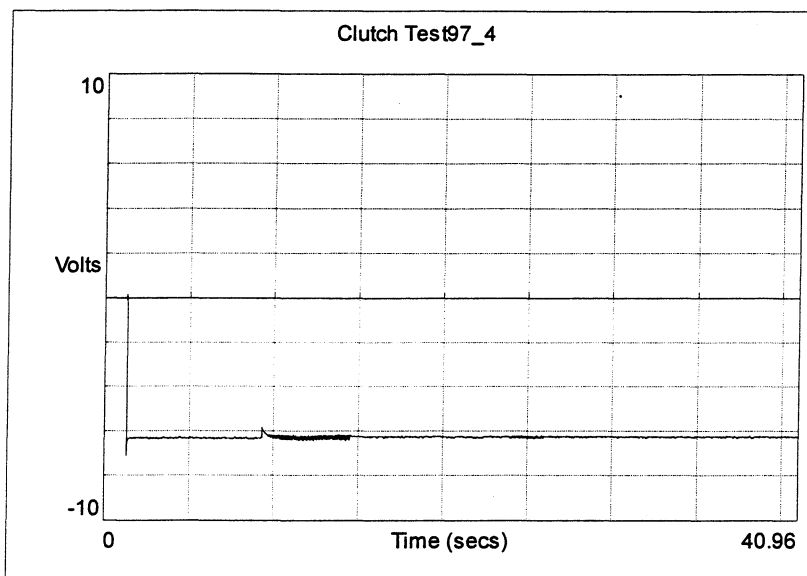
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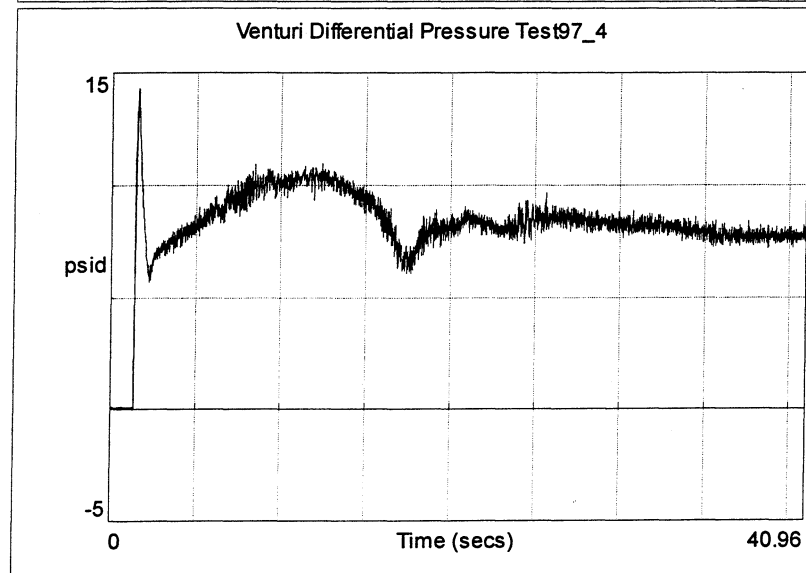
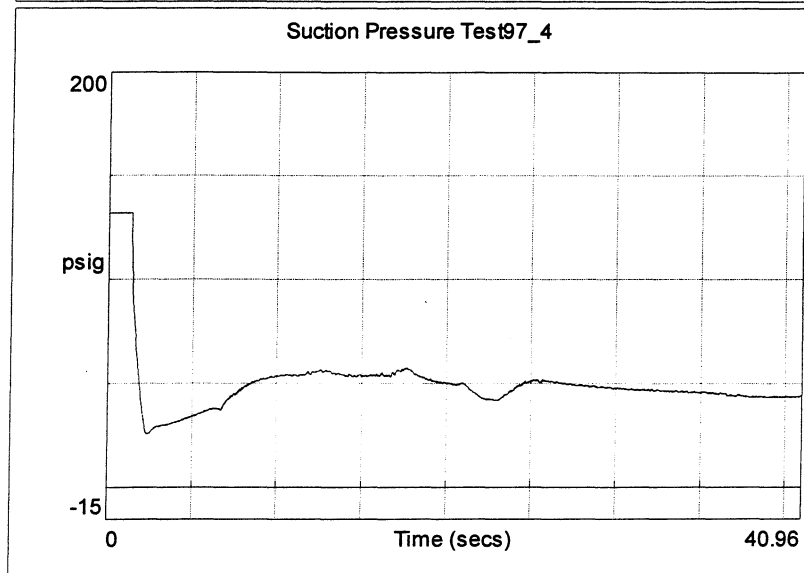
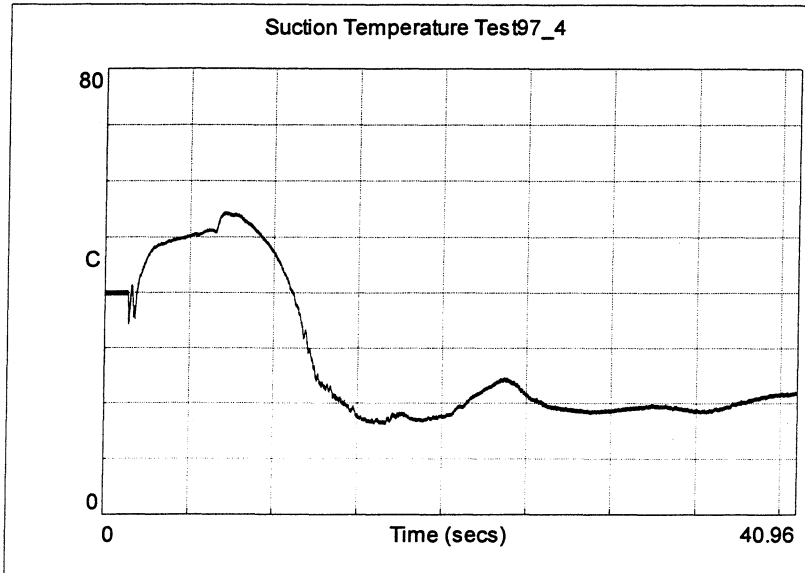


Suction Line Density Test97_3









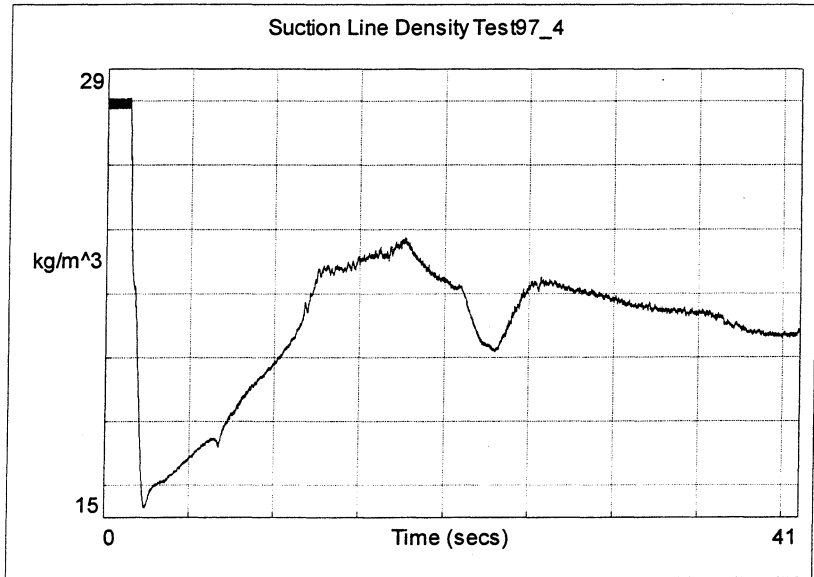
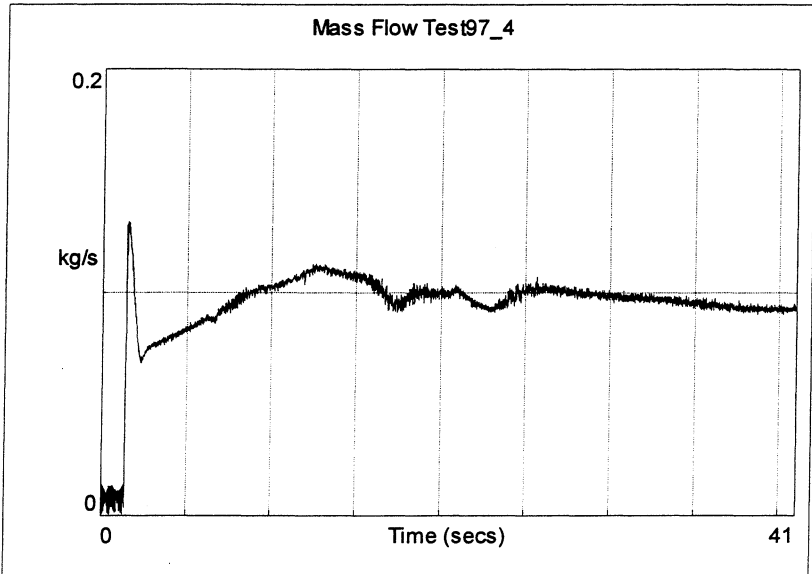
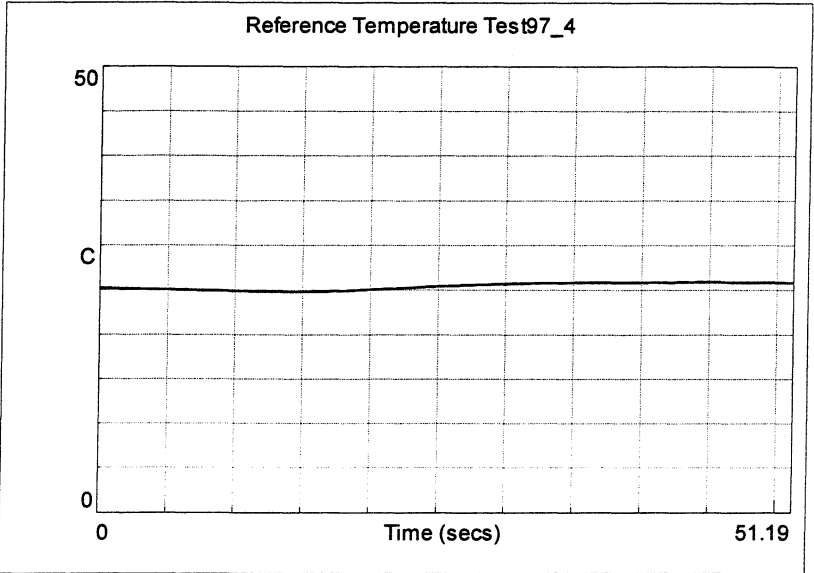
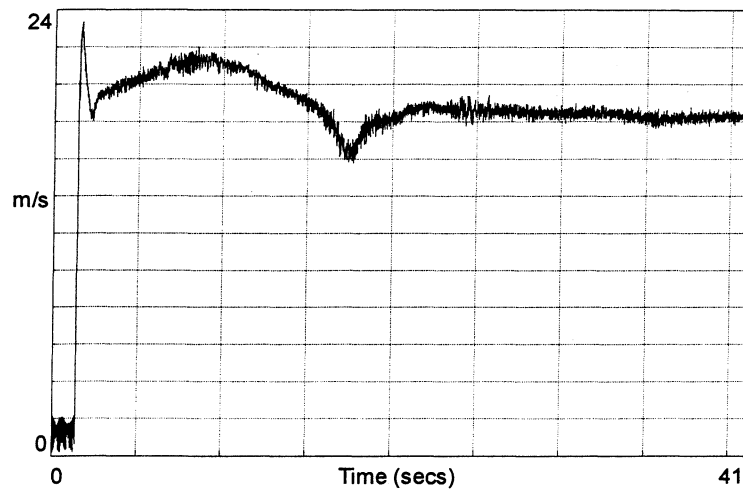
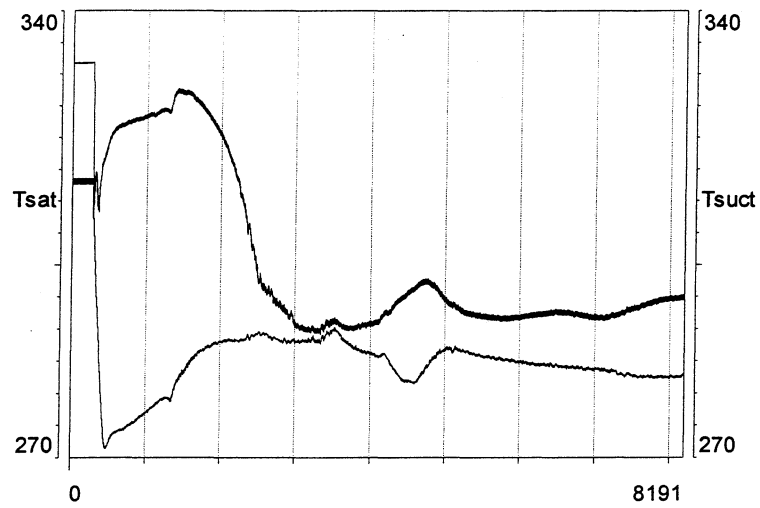
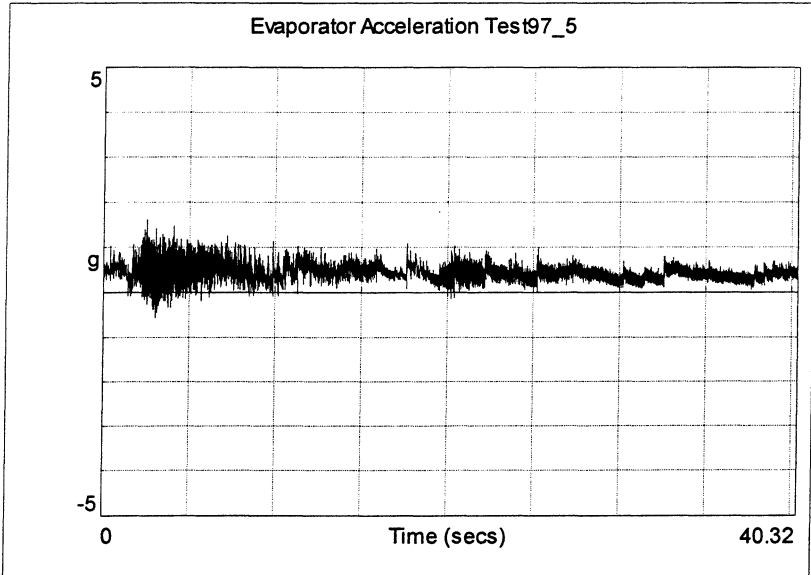
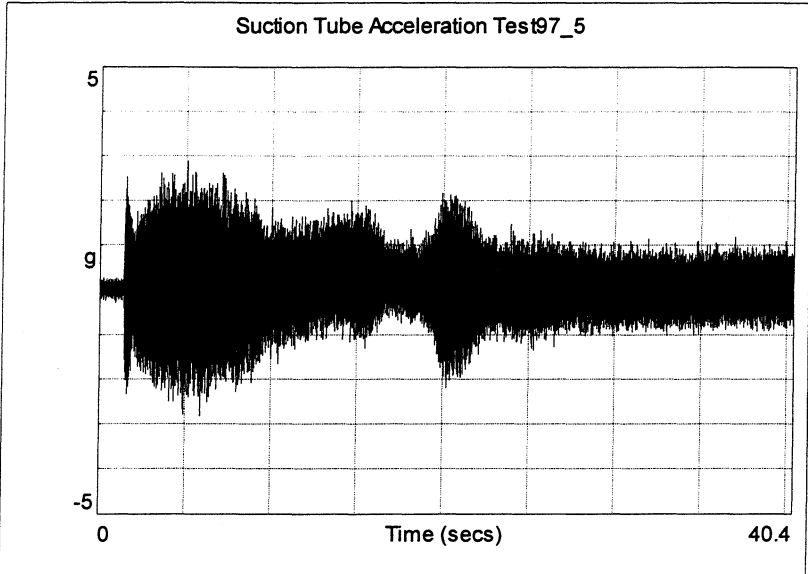
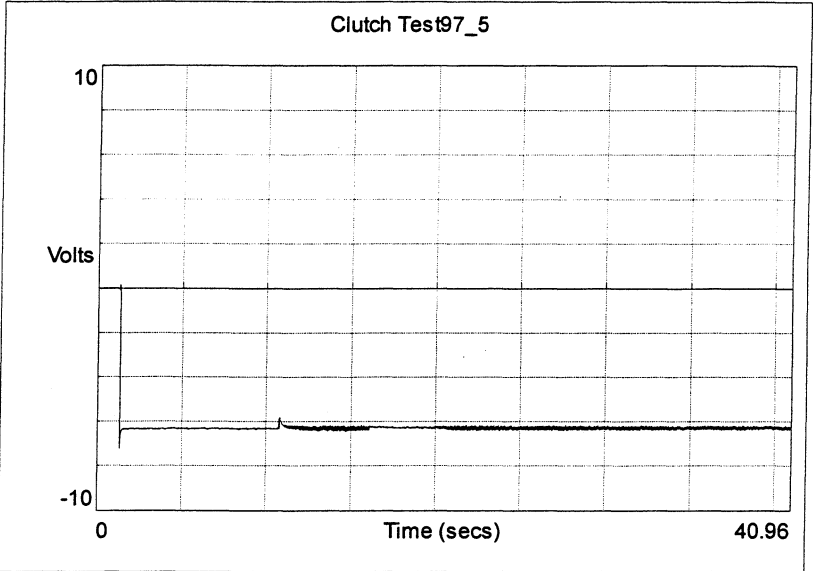


Plate Evaporator Velocity (6 1/2 Plates) Test997_4

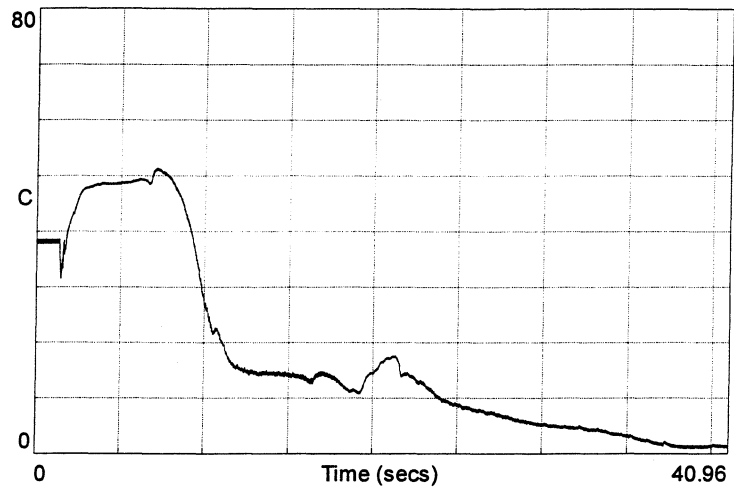


Comparison of Saturation and Suction Temperature Test97_4

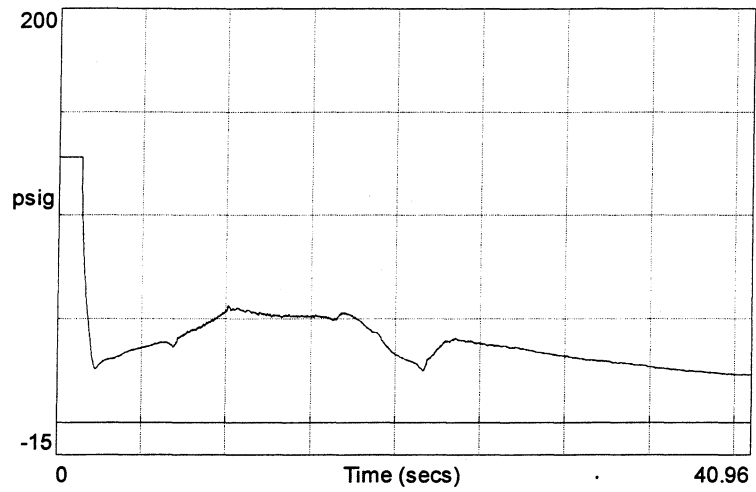




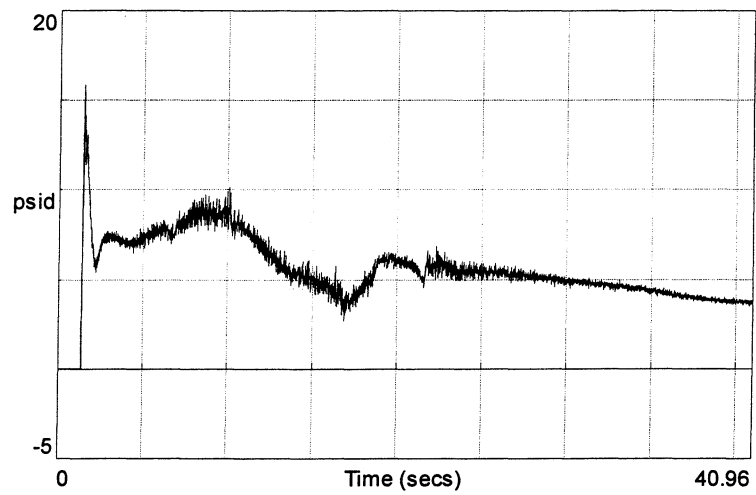
Suction Temperature Test97_5



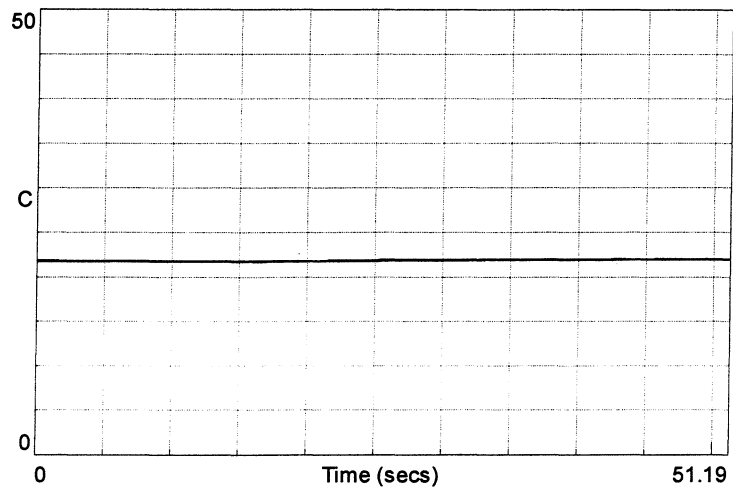
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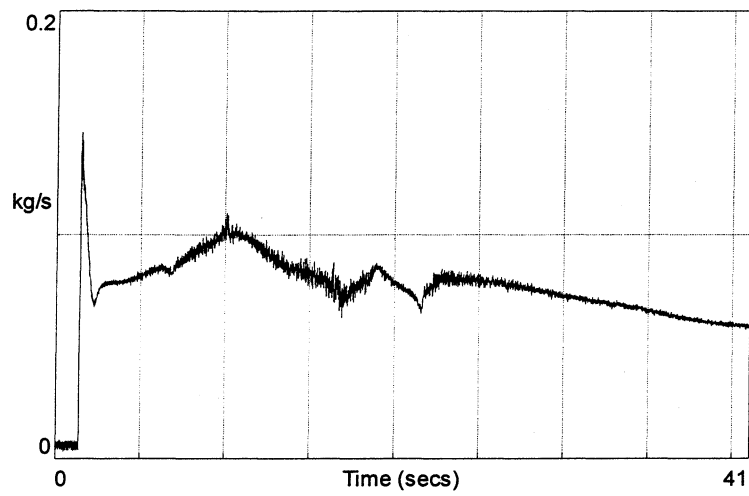
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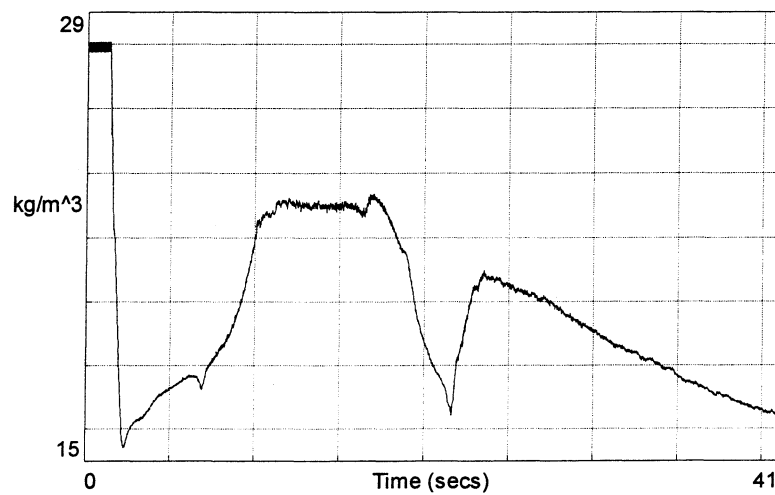
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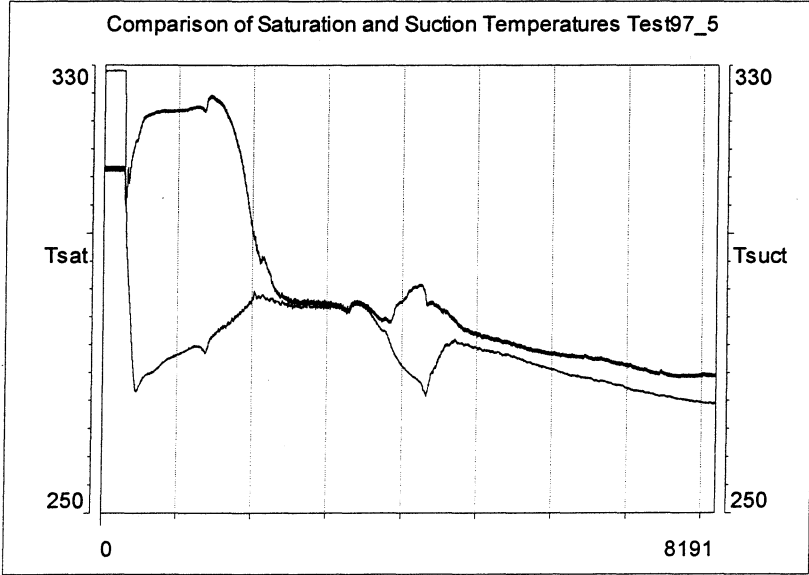
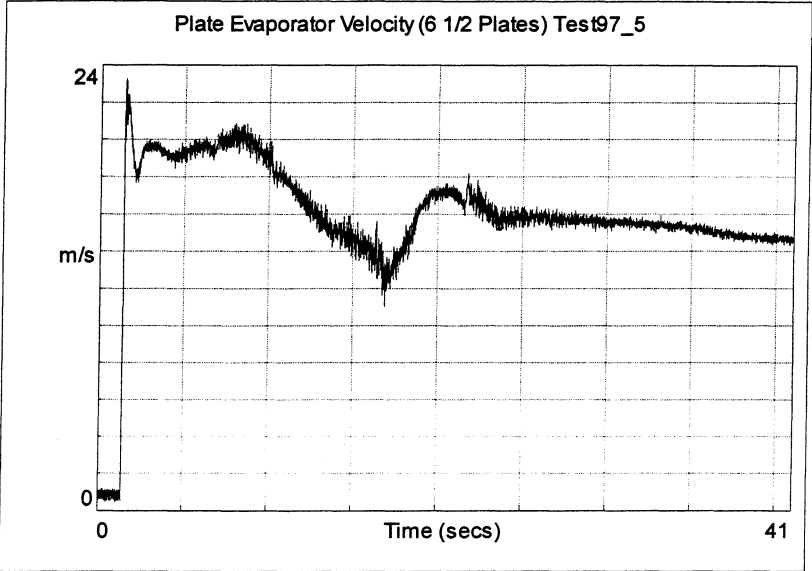


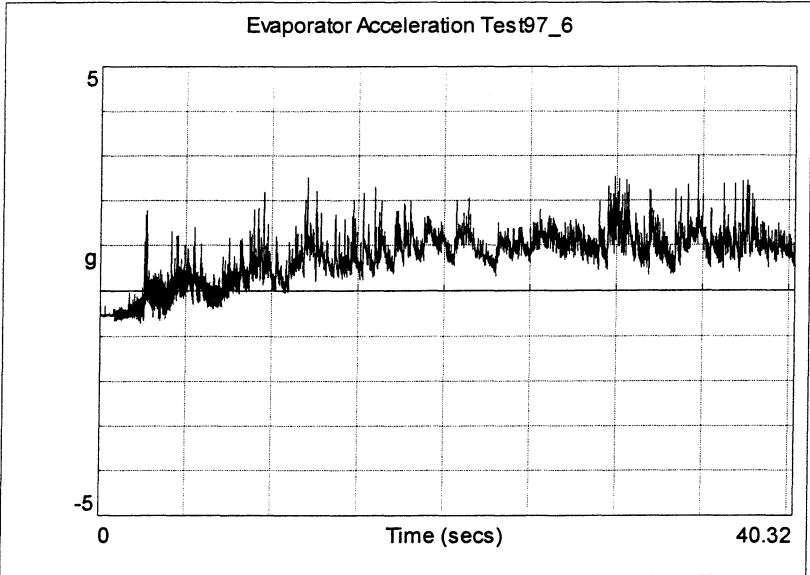
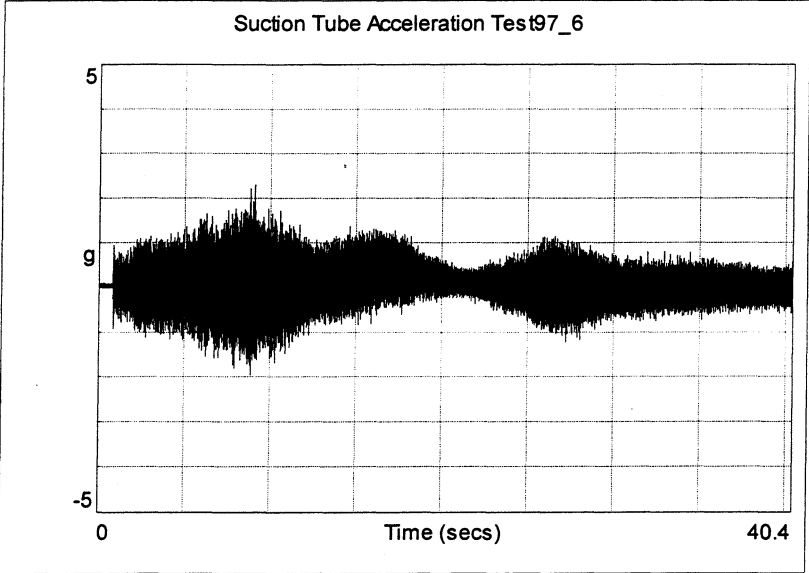
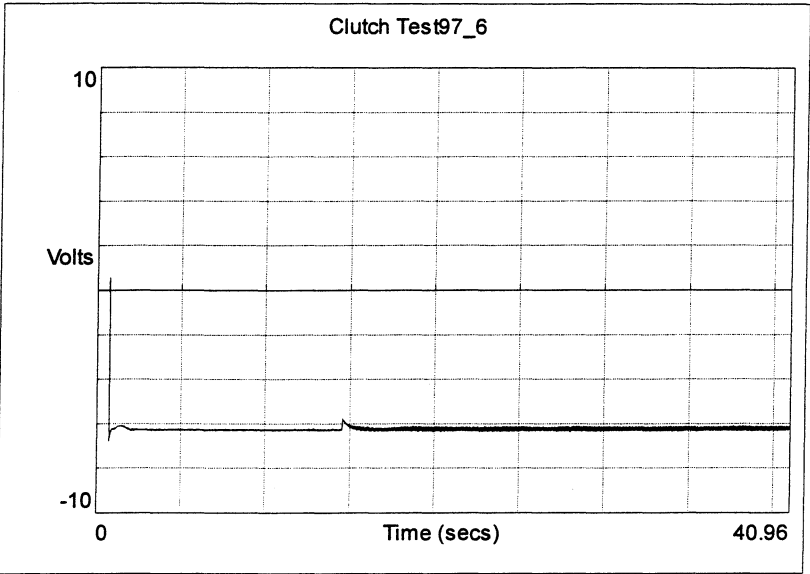
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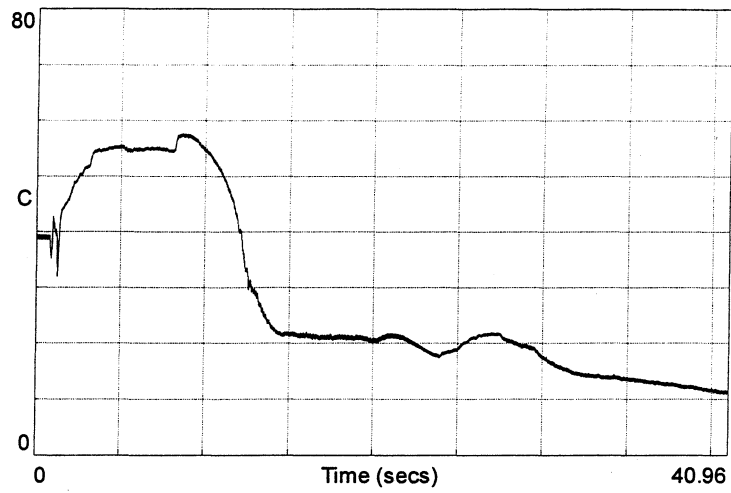
Suction Line Density Test97_5



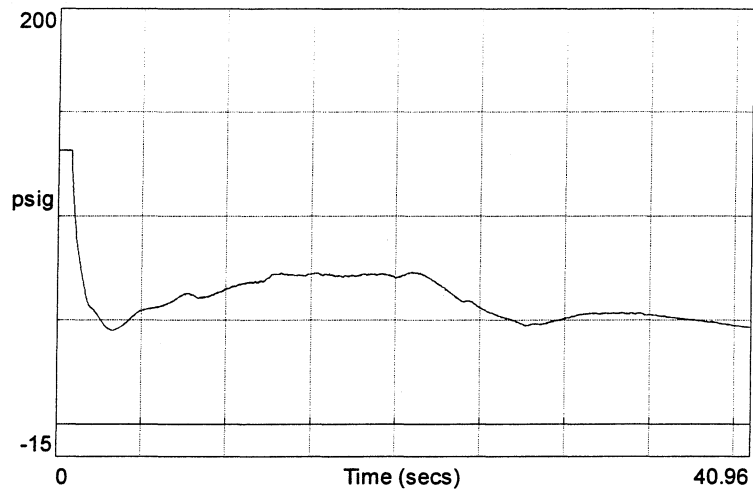




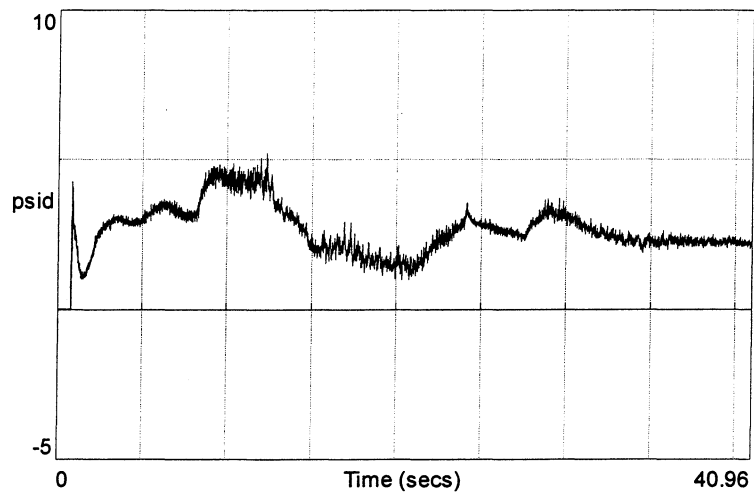
Suction Temperature Test97_6



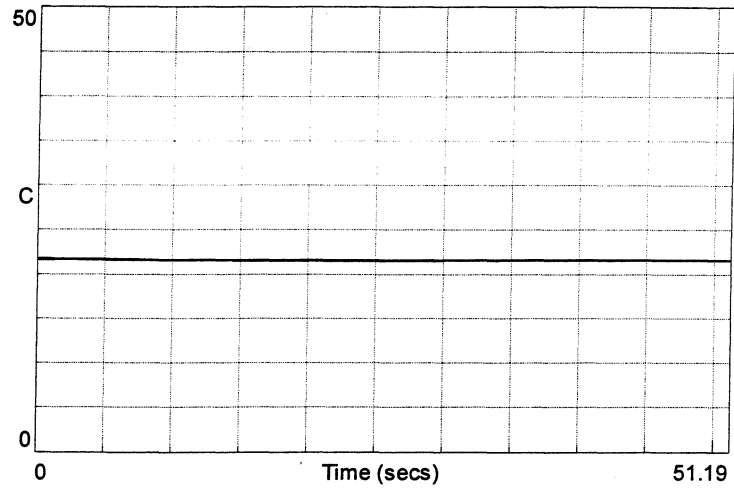
Suction Pressure Test97_6



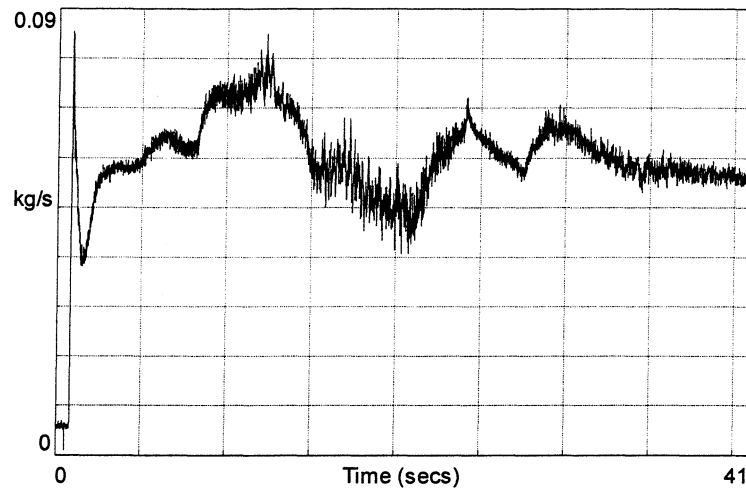
Venturi Differential Pressure Test97_6



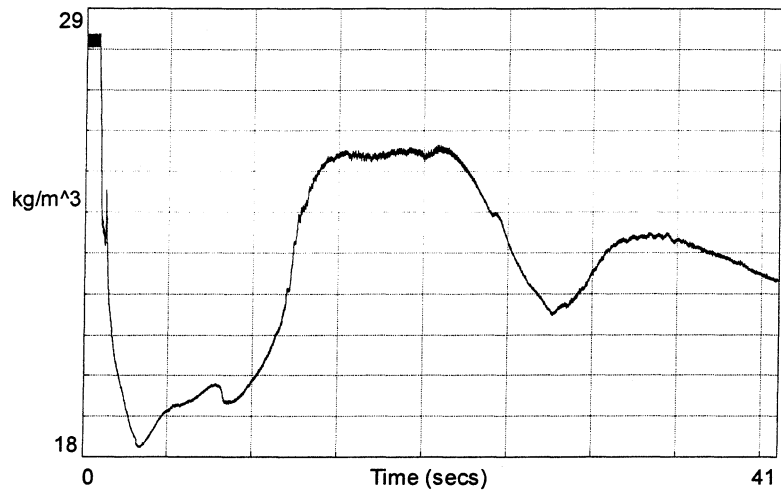
Reference Temperature Test97_6

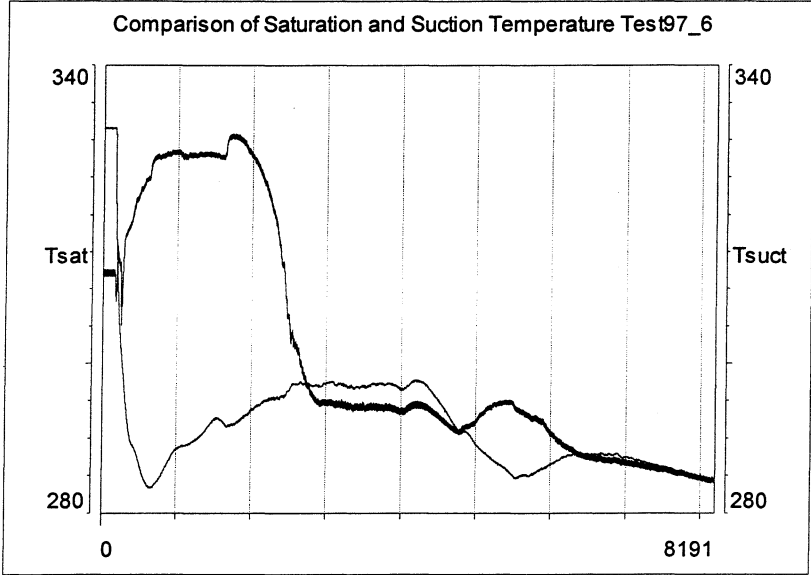
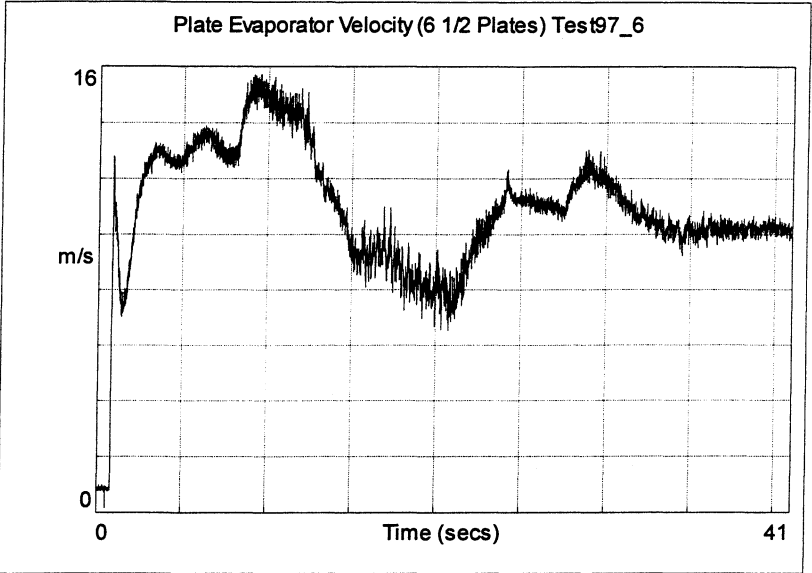


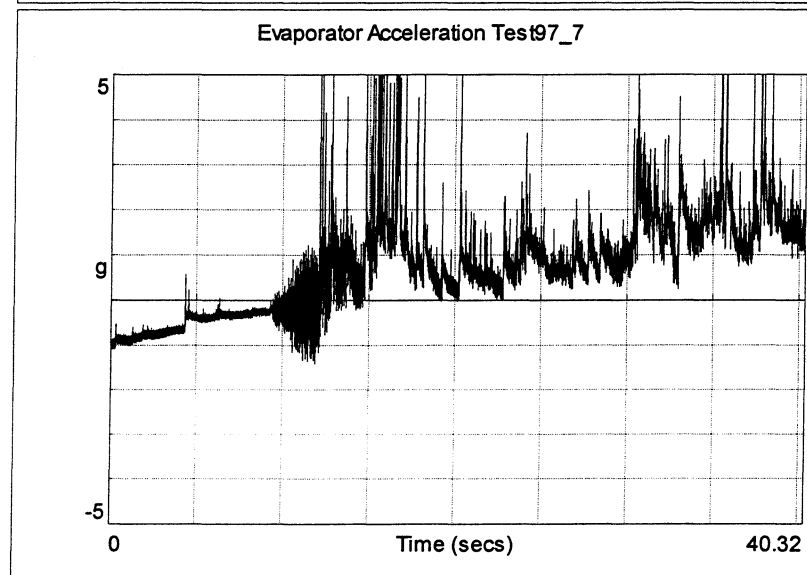
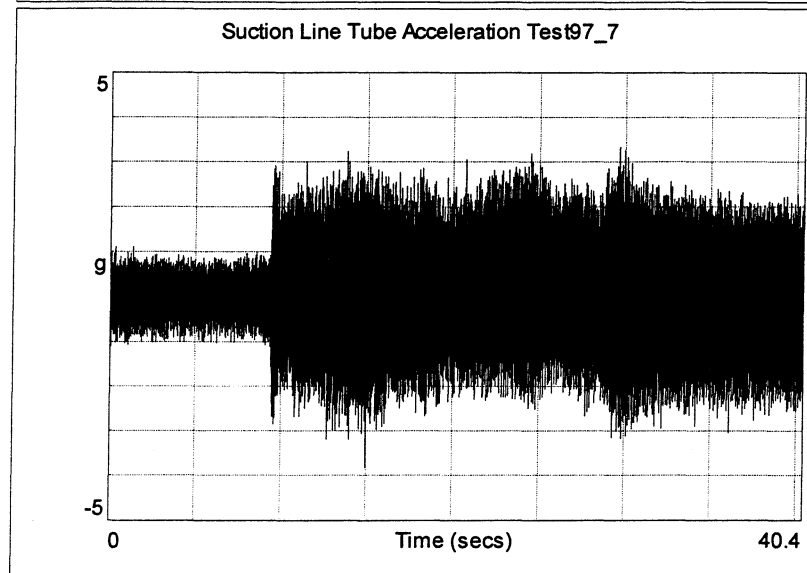
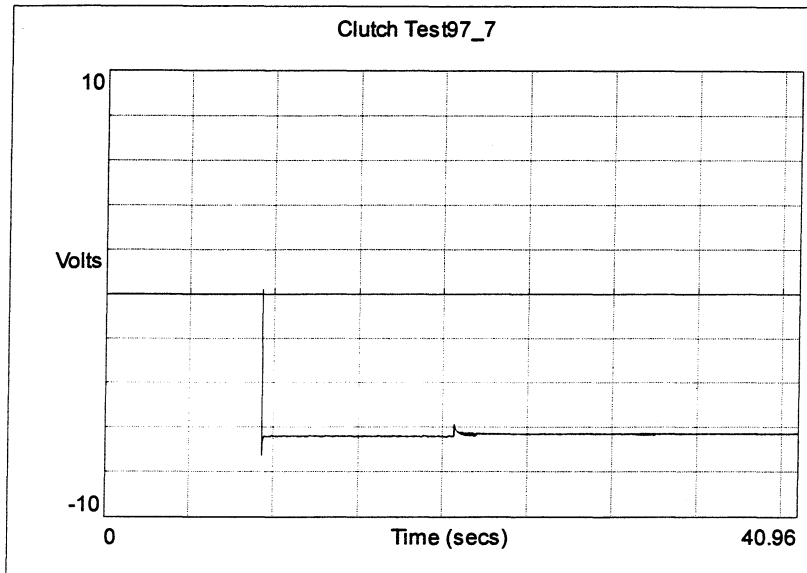
Mass Flow Test97_6

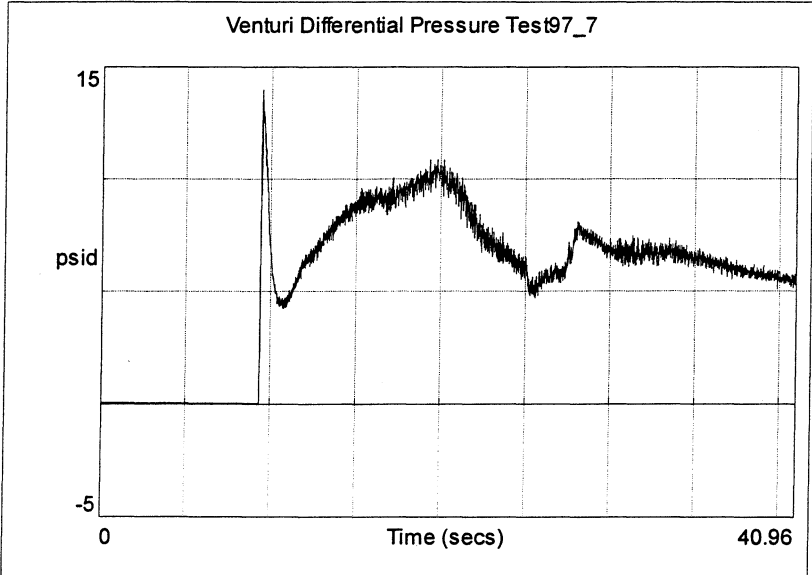
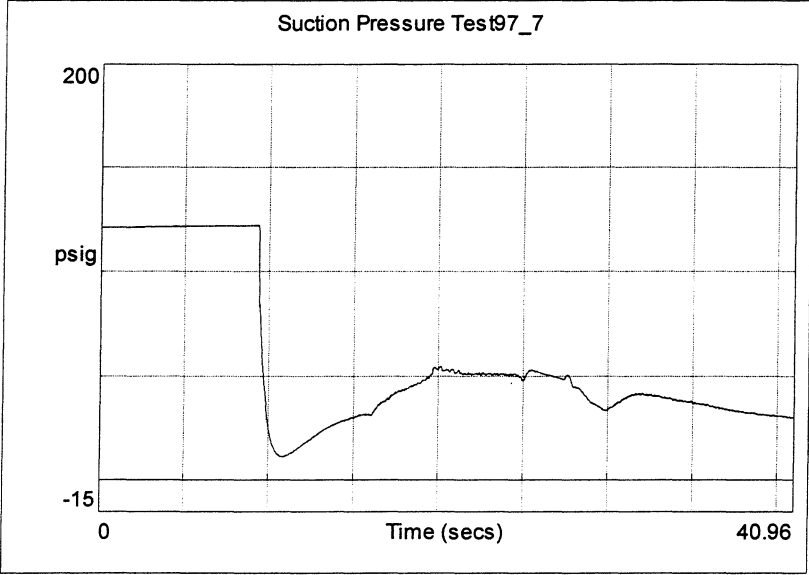
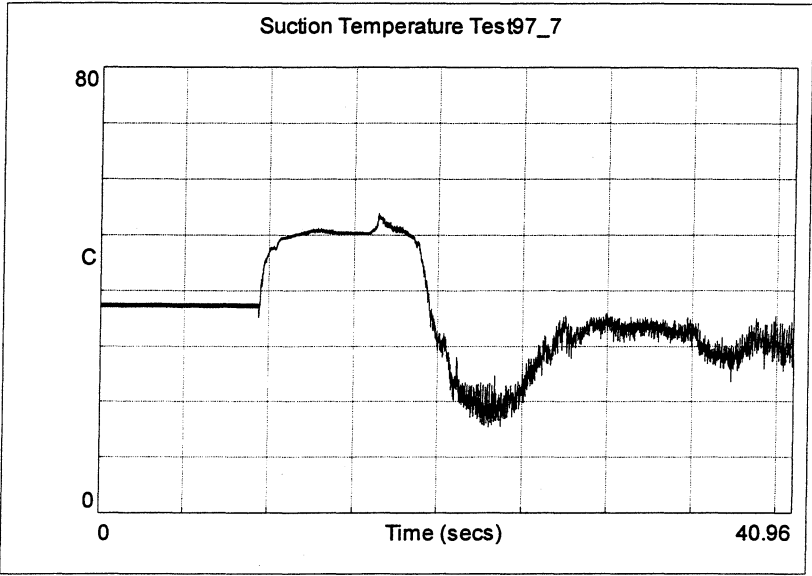


Suction Line Density Test97_6

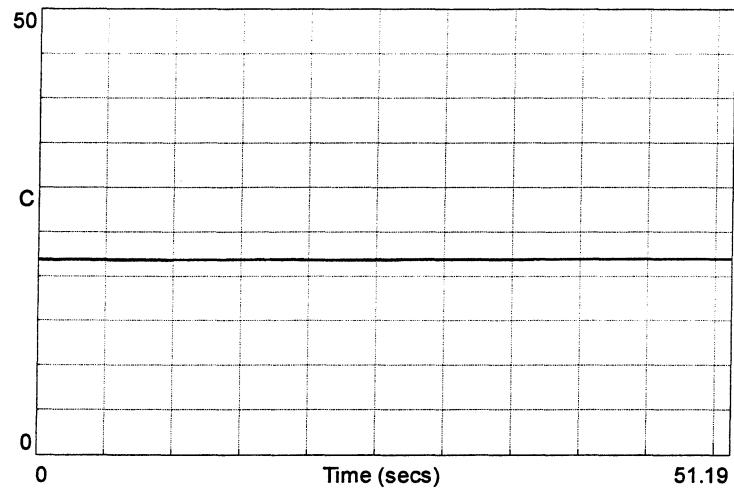




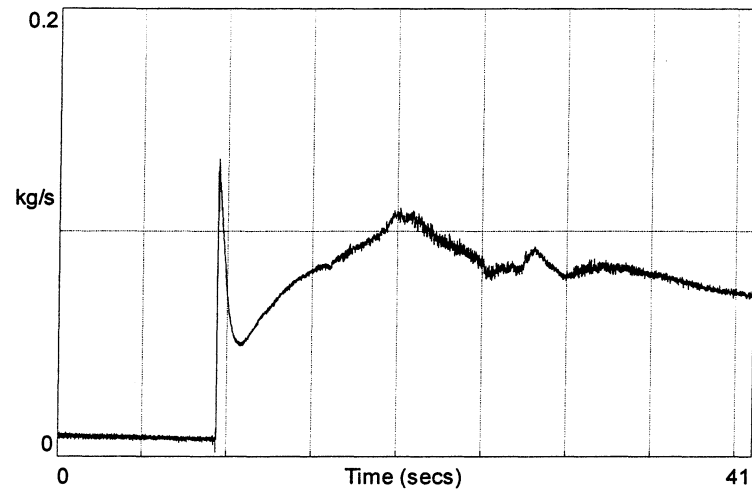




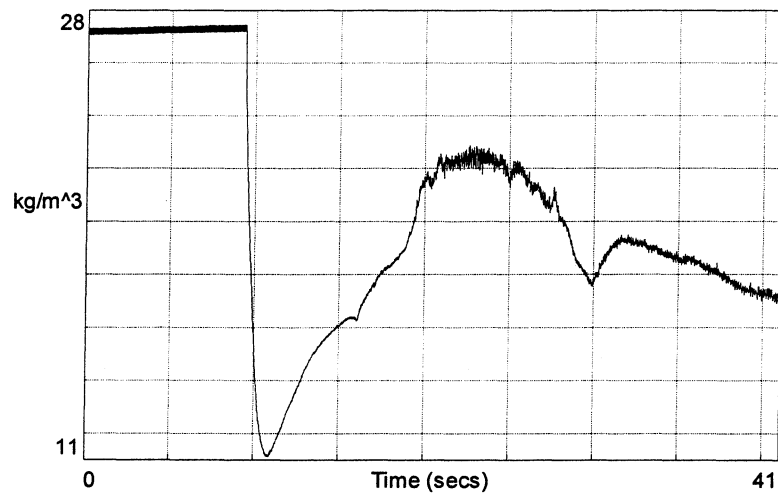
Reference Temperature Test97_7

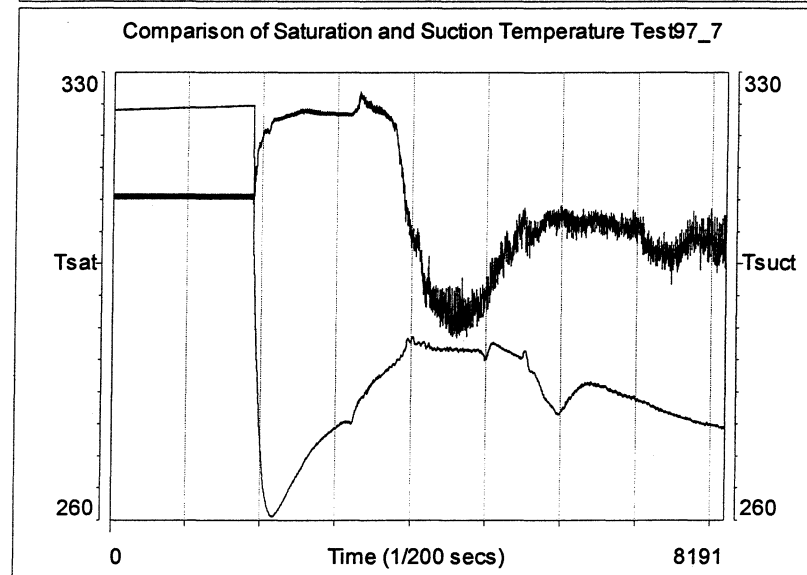
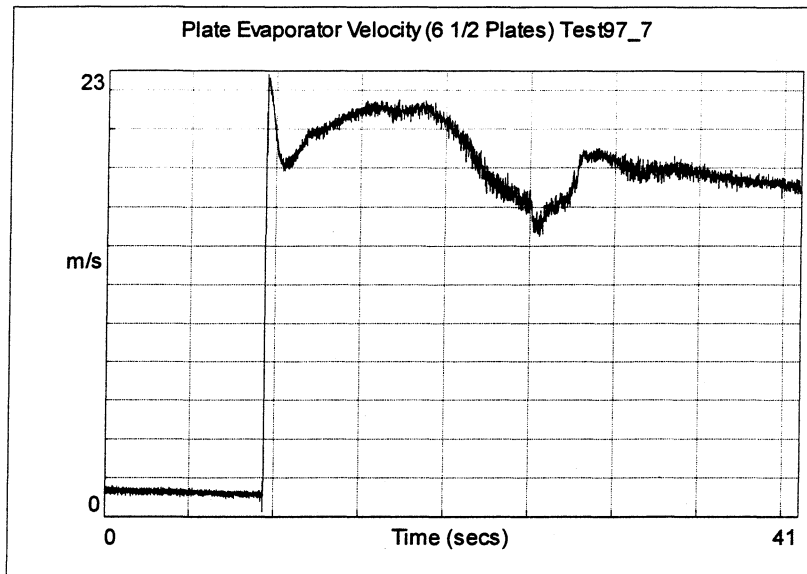


Mass Flow Test97_7



Suction Line Density Test97_7





Appendix B

Density Estimation Equations.

$$R = \frac{8.314}{102}$$

$$T_c = 374.2$$

$$P_c = 4067$$

$$a = 0.4275 \cdot R^2 \cdot \frac{T_c^{2.5}}{P_c}$$

$$b = 0.08664 \cdot R \cdot \frac{T_c}{P_c}$$

$$\rho_{\text{pred}} = c \cdot \left[\frac{0.5 \cdot \left(\sqrt{T_k} \cdot (b \cdot P_{f1} + R \cdot T_k) + \sqrt{-4 \cdot a \cdot P_{f1} \cdot \sqrt{T_k} + T_k \cdot (b \cdot P_{f1} + R \cdot T_k)^2} \right)}{P_{f1} \cdot \sqrt{T_k}} \right]^{-1}$$

$$T_k = T_{f1} + 273.2$$

$$T_{f1} = t_{\text{sat}} + 50$$

$$t_{\text{sat}_{\text{cal}}} = -38.29 + 1.163 \cdot P_{\text{psi}} - 0.00758 \cdot P_{\text{psi}}^2 + 0.00002832 \cdot P_{\text{psi}}^3 - 4.115 \times 10^{-8} \cdot P_{\text{psi}}^4$$

$$P_{f1} = P_{\text{psi}} \cdot \left[6.895 \cdot \frac{kPa}{psi} \right]$$

$$\rho = \rho(R134a, P=P_{f1}, T=T_{f1})$$

$$t_{\text{sat}} = T \left[R134a, P=P_{\text{psi}} \cdot \left(6.895 \cdot \frac{kPa}{psi} \right), x=0.5 \right]$$

$$\text{error} = 100 \cdot \left[\frac{|\rho - \rho_{\text{pred}}|}{\rho_{\text{pred}}} \right]$$

$$c1 = 1.02 + 0.00006632 \cdot P_{f1} + 6.124 \times 10^{-8} \cdot P_{f1}^2 - 6.001 \times 10^{-11} \cdot P_{f1}^3$$

$$c2 = -0.001539 \cdot T_{f1} + 0.00002327 \cdot T_{f1}^2 - 2.645 \times 10^{-8} \cdot T_{f1}^3 - 2.201 \times 10^{-7} \cdot P_{f1} \cdot T_{f1}$$

$$c3 = -2.714 \times 10^{-8} \cdot P_{f1} \cdot T_{f1}^2 + 2.783 \times 10^{-10} \cdot P_{f1}^2 \cdot T_{f1} + 1.173 \times 10^{-11} \cdot P_{f1}^2 \cdot T_{f1}^2$$

$$c = c1 + c2 + c3$$

Mass Flow Estimation Equations.

$$Dt = 0.375 \cdot 0.0254$$

$$Di = 0.8 \cdot 0.0254$$

$$At_{\text{venturi}} = \pi \cdot \frac{Dt^2}{4}$$

$$Ck = 0.948$$

$$k = 1.09$$

$$DP_{\text{psid}} = 3$$

$$Tf1 = 25$$

$$Pf1 = 90 \cdot \left[6.895 \cdot \frac{kPa}{psi} \right]$$

$$\delta_P = DP_{\text{psid}} \cdot \left[6895 \cdot \frac{Pa}{psi} \right]$$

$$\rho = \rho(R134a, T=Tf1, P=Pf1)$$

$$\dot{m} = Ck \cdot Y \cdot At_{\text{venturi}} \cdot \left[\sqrt{\frac{2 \cdot \delta_P \cdot \rho}{1 - \left(\frac{Dt}{Di} \right)^4}} \right]$$

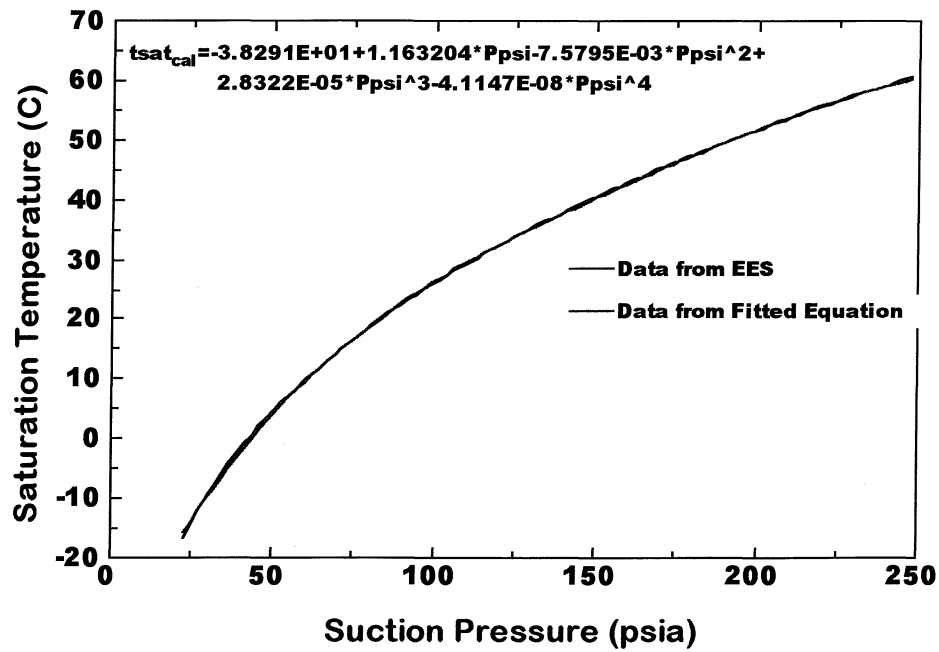
$$Y = \left[\frac{\left(\left[1 - \left(\frac{Dt}{Di} \right)^4 \right] \cdot \left[\frac{k}{k-1} \right] \right) \cdot \left(\frac{pf2}{Pf1} \right)^{\left(\frac{2}{k} \right)} \cdot \left(1 - \left[\frac{pf2}{Pf1} \right]^{\left[\frac{k-1}{k} \right]} \right)}{\left(1 - \left[\frac{Dt}{Di} \right]^4 \right) \cdot \left[\frac{pf2}{Pf1} \right]^{\left[\frac{2}{k} \right]} \cdot \left(1 - \frac{pf2}{Pf1} \right)} \right]^{(1/2)}$$

$$pf2 = Pf1 - \delta_P \cdot \left[0.001 \cdot \frac{kPa}{Pa} \right]$$

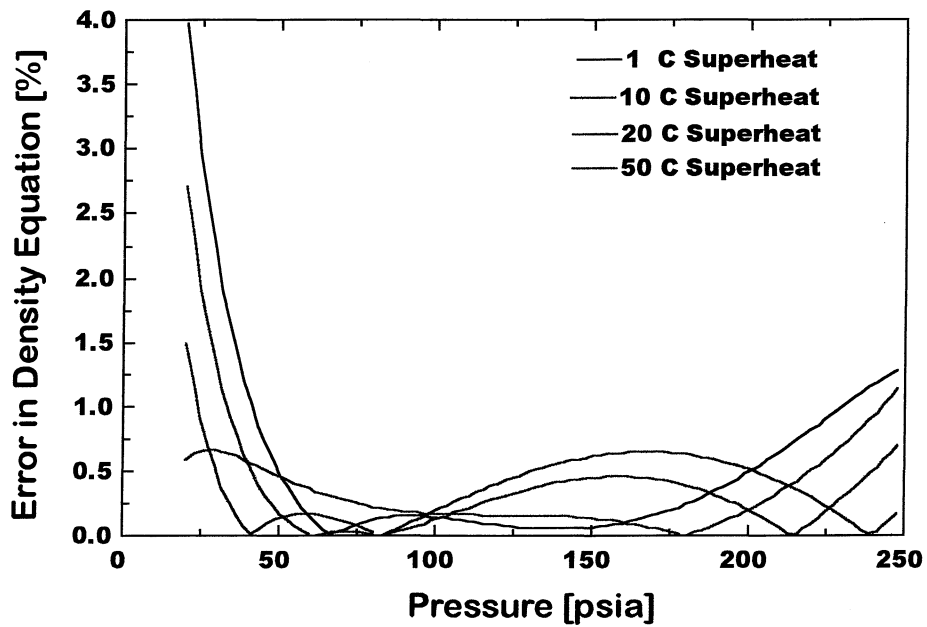
$$T_{\text{sat}} = T(R134a, P=Pf1, x=0.5)$$

$$Dt_{\text{superheat}} = Tf1 - T_{\text{sat}}$$

Saturated Temperature Equation Fit.



Density Equation Accuracy Check.



Appendix C: Photographs

